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THE INFLUENCE OF SOIL AND ROCK PROPERTIES ON THE DIMENSIONS OF EXPLOSION-PRODUCED CRATERS

Larry A. Dillon
Maj USAF

The Texas A&M Research Foundation

TECHNICAL REPORT NO. AFWL-TR-71-144

February 1972

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base
New Mexico

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FOREWORD

This report was prepared by the Texas A&M Research Foundation, College Station, Texas, under Contract F29601-70-C-0032. This research was performed under Program Element 61102H, Project 5710, Task SA102, and was funded by the Defense Nuclear Agency (DNA).

Inclusive dates of research were February 1970 through October 1971. The report was submitted 27 December 1971 by the Air Force Weapons Laboratory Project Officer, Major Neal E. Lamping (DEV-G). The former project officer was Captain Peter M. Terlecky.

This project was supervised by Dr. Louis J. Thompson whose help and encouragement made it possible. Mr. Steve Clark provided invaluable research aid. Captain Paul Knott provided and modified the computer plotting program.

Appreciation is extended to Mr. Robert W. Henny, AFWL; Mr. Luke J. Vortman, Sandia Laboratories; Mr. Robert W. Terhune, Lawrence Radiation Laboratory; and to Lt Colonel Robert L. LaFranz and the many helpful people of the US Army Engineer Nuclear Cratering Group for providing data.

This technical report is the result of research performed at the Graduate College of Texas A&M University in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Civil Engineering for Major Larry A. Dillon.

This technical report has been reviewed and is approved.

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ABSTRACT

(Distribution Limitation Statement B)

Analysis of data from published cratering experiments shows the effect of soil and rock properties on the apparent dimensions of explosion produced craters. More than 200 cratering tests and related material properties were cataloged. The data consisted of 10 nuclear events whose yields varied from 0.42 to 100 kilotons and about 200 high explosive events whose yields varied from 1 to 1 million pounds of TNT. The different test sites included materials for which the density ranged from 60 to 170 pounds/cubic foot.

By regression analysis, using bell shaped curves, prediction formulas were developed for the apparent crater radius, depth, and volume as a function of charge weight and depth of burst for eight different types of materials. The bell curves were normalized using material properties and prediction equations were generated using all the data. These general equations were then studied to determine the specific effects of the material properties on resultant apparent crater dimensions.

Material properties are highly important in determining the size of explosion-produced craters and some of the more important properties are unit weight, degree of saturation, shearing resistance and seismic velocity. Previous investigators have been somewhat negligent in measuring material properties for past cratering experiments and no real data analysis can be made until the variables are either controlled or measured. Material properties which should be measured for future tests should at least include the above properties and if possible the material's energy dissipation and bulking characteristics. Better yet a reasonably simple theory of cratering is needed which will better define the material properties governing cratering mechanics.

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NOTATION

The following symbols are used in this report:

A_i = coefficient of bell curve in coded form;

B_i = coefficient of bell curve;

C_i = general coefficient;

D = crater depth;

D_a = maximum depth of the apparent crater;

Dob = depth of burst;

E_v = vaporization energy;

G_s = grain bulk specific gravity;

H_{al} = apparent crater lip crest height;

L_a = linear apparent crater dimension (radius, depth, or cube root of volume);

M = general material property;

R = crater radius;

R_a = radius of apparent crater;

R_m^2 = multiple correlation coefficient

S = degree of saturation;

SGZ = surface ground zero;

TNT = the high explosive, trinitrotluene;

V = crater volume;

V_a = volume of apparent crater;

W = weight of explosive;

NOTATION (Continued

ZP = zero point-effective center of explosion energy;

c = seismic velocity;

exp = exponential (e);

g = acceleration due to gravity;

ln = natural logarithm;

m = the divisor portion of the scaling exponent, 1/m;

tan ϕ = tangent of the angle of shearing resistance;

x,y = rectangular Cartesian coordinates;

γ = total unit weight;

γ_d = dry unit weight;

ρ = mass unit weight.

SECTION I

INTRODUCTION

Over the past several years, because of intensified studies of possible engineering applications of nuclear energy, increased attention has been devoted to the problem of cratering by explosives. One of the most obvious peaceful applications of nuclear explosives is that of earth excavation, as might be considered for the construction of harbors, dams, or canals. Prediction and design for survival of silo-launched missile systems has also added urgency to these studies.

Although most investigators have recognized that the size of a crater obtained from an explosive charge depends upon the media in which it is detonated, properties describing the media which relate to the dimensions of this crater are somewhat obscure. The primary purpose of this investigation, then, was to determine which engineering properties normally measured for earth and rock materials could be related to the size of a crater created by an explosive charge.

A large number of cratering experiments have been conducted in various media (15,60,87). These experiments primarily

provided data on the effect of explosive energy and depth of burst on crater dimensions. Although the experiments number in the thousands and although engineering material properties were measured for a good percentage of these experiments, very little has been reported which relate these material properties to the final crater geometry. Previous investigators seem to have been of two minds: (1) Because material properties vary greatly within one media in one location and because accurate measurement of these properties is often difficult, the best approaches are to ignore completely the material properties or to over simplify and let the material be described by one constant in a particular prediction relationship; and (2) because the cratering process is so complicated, extensive measurement of material properties both in the field and in the lab are required to describe the media to be subjected to an explosive charge. It would appear that the better solution lies somewhere between these two extremes.

SECTION II

GENERAL CONCEPTS AND TERMINOLOGY

This section of the report presents basic concepts concerning the parameters and mechanisms involved in the explosive formulation of craters. The effect of explosive weight, depth of burst and type of material are discussed. Terminology generally associated with the cratering process is also presented.

General Description of the Cratering Process (63). When an explosion occurs at or near the surface of a soil or rock-like material, a crater is formed (see Fig. 1). The size of this crater depends on at least four factors: (1) The energy released by the explosion; (2) the position of the explosive relative to the surface; (3) the material type; and (4) gravitational effects. The influence of the energy release is obvious, the larger the charge, the larger the crater. When the charge is on or above the ground surface, cratering effects are small. As the charge is placed deeper in the ground, the size of the crater increases, both in radius and depth, until a maximum is reached after which the crater size will decrease with increasing depth of burial. For deeply buried explosives, an underground cavity is formed. The surface itself may be raised and may eventually subside to form a depression crater. For materials which bulk during the explosion process, there is a region where rubble mounds will be formed. Mounding and

CRATER PROFILE

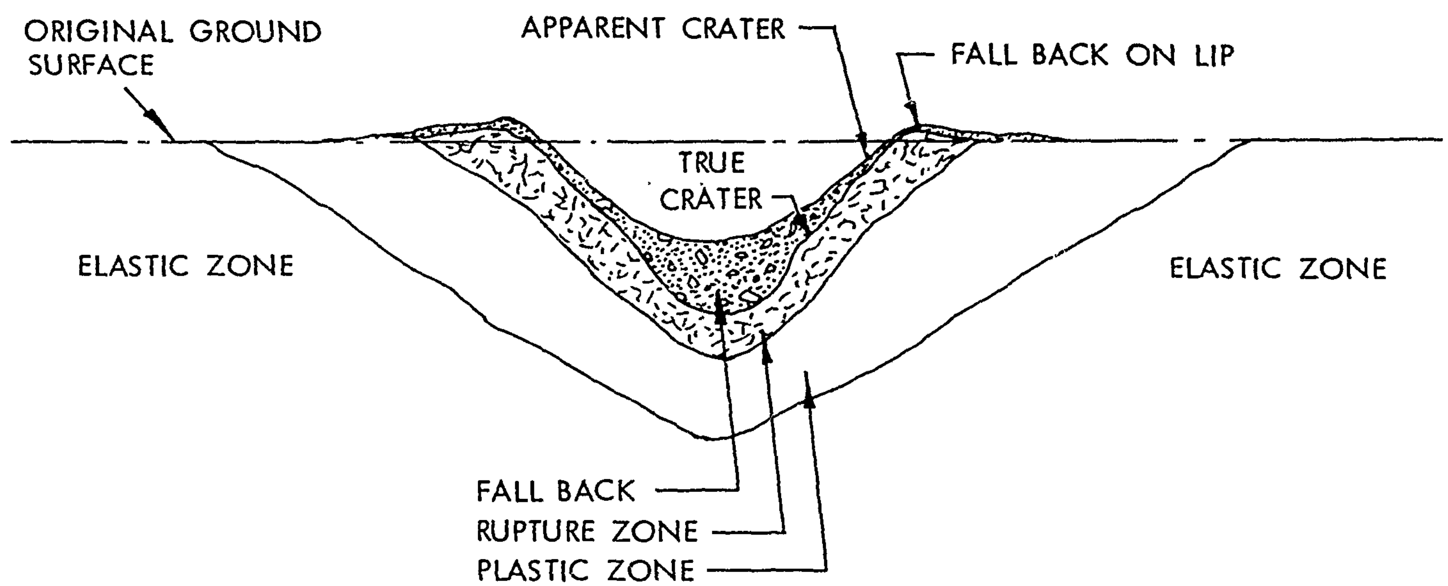


FIG. 1. CROSS SECTION OF A TYPICAL CRATER

subsidence depend upon the material and depth of burst. The larger the material's energy-dissipative properties, the smaller the crater size will be. The size of the apparent crater is affected by the amount of fall-back material, that is, the material originally ejected which returns under gravity to the crater zone.

Crater Terminology (22,27). A few basic terms and definitions are presented to provide an acquaintance with significant zones, dimensions and terminology used throughout the report. Again referring to Fig. 1, the cross section of a typical crater and the adjacent zones of disturbance are shown.

The apparent crater is defined as that portion of the visible crater which is below the preshot ground surface. The apparent crater would be the net design excavation for most engineering applications.

The true crater is defined as the boundary (below preshot ground level) between loose, broken, disarranged fall-back materials and the underlying rupture zone material which has been crushed and fractured, but has not experienced significant displacement or disarrangement. The true crater boundary is not a distinct surface of discontinuity, but rather a zone of transition between the rupture zone and fall-back materials.

The apparent lip is composed of two parts, the true lip, which is formed by the upward displacement of the ground surface, and the ejecta material deposited on the true lip.

The visible crater comprises the apparent crater and the apparent lip.

The fall-back consists of natural materials which have experienced significant disarrangement and displacement and have come to rest within the true crater.

The ejecta consists of material thrown out above and beyond the true crater.

The rupture zone is that zone extending from the true crater boundary in which crushing and fracturing have occurred.

The plastic zone is that portion of the cratered medium beyond the rupture zone in which permanent deformation has occurred.

The elastic zone extends beyond the plastic zone and is characterized by the absence of blast produced fissures, cracks, or permanent displacement of material.

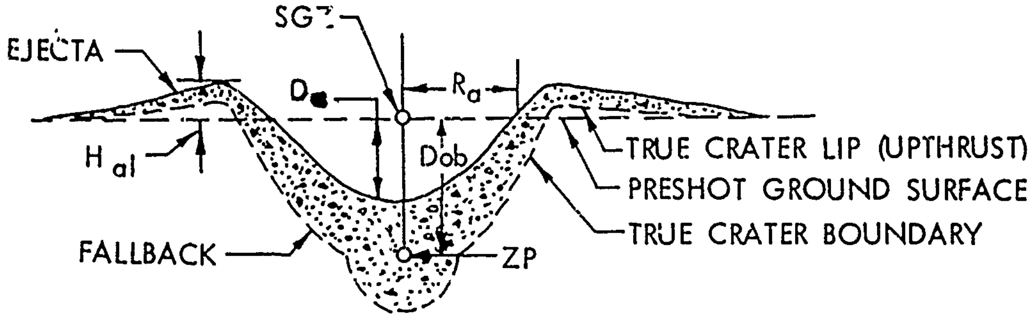
The optimum depth of burst is that depth for a specified explosive charge which produces the largest crater. For any one charge in any one medium, there may be three optimum depths of burst depending upon whether the largest radius, depth, or volume is desired.

A scaled dimension refers to a particular crater dimension divided by the explosive weight of the charge to some power (usually between 1/4 and 1/3). If the proper exponent is selected, scaling between different sized explosive charges for a particular scaled depth of burst is then possible.

Crater dimensional data used in this report along with accompanying symbols and definitions is given in Fig. 2. A detailed description of all pertinent single-charge crater dimensional data can be found in reference 22.

<u>Cratering Mechanisms (27,38,46)</u>. The primary mechanisms or processes which produce craters in rock or soil may be categorized as: (1) Vaporization and melting of the material immediately surrounding the source of a nuclear explosion; (2) crushing, compaction, fracturing, and plastic deformation of the medium closely surrounding the explosive gas cavity; (3) spalling of the surface; (4) acceleration of the fractured material overlying the explosion by trapped gases; and (5) subsidence and fall-back of the material as the explosive pressure goes to zero and the force of gravity predominates.

The tremendous pressures resulting from an explosive detonation (10-100 million atmospheres for a nuclear explosive) generate a shock wave which propagates as a high-pressure discontinuity. This high-pressure discontinuity, or shock front, transfers energy to the medium, and in turn, alters the physical characteristics of the medium. In the immediate vicinity of a nuclear explosion, vaporization and melting of the material occurs. The peak pressure in the shock wave diverges and energy is expended in doing work on the medium. When the pressure and shear stress levels exceed the dynamic crushing strength of the material, work on the medium is manifested in crushing,



R_a - Radius of apparent crater measured at preshot ground surface

D_a - Maximum depth of apparent crater below preshot ground surface

H_{al} - Apparent crater lip crest height above preshot ground surface

V_a - Volume of apparent crater below preshot ground surface

Dob - Depth of burst (distance to ZP from SGZ)

ZP - Zero Point-effective center of explosion energy

SGZ - Surface Ground Zero (point on surface vertically above ZP)

FIG. 2. DIMENSIONAL DATA FOR SINGLE CHARGE CRATER

heating, displacement, and deformation of the material. When the compressive and shear waves which propagate from the detonation encounter the surface, a tensile wave and another shear wave are reflected, and since the tensile strengths of rock and soil are much less than their compressive strengths, spalling of the surface occurs. Rock also tends to spall along pre-existing fractures and planes of weakness. The first two processes may be classified as short term mechanisms since they last only a fraction of a second. Gas acceleration, on the other hand, is a comparatively long-period process which imparts motion to the material around the explosion by the adiabatic expansion of gases trapped in the cavity. Finally the force of gravity pulls all the overlying fractured and crushed material into the cavity and pulls all the loose material thrown into the air by spalling and gas acceleration back into and around the crater. What remains is an apparent crater underlayed with crushed and displaced material.

Effects of Depth of Burst. The part each of the above mechanisms play in producing a crater is very strongly dependent upon the scaled depth of burst of the explosion and the medium in which the detonation occurs. Shown in Fig. 3 are typical crater cross sections in rock showing the effect of depth of burst. As summarized by Nordyke (46), Fig. 4, the contribution of each of the mechanisms to apparent crater depth as a function of the charge depth of burst is shown.

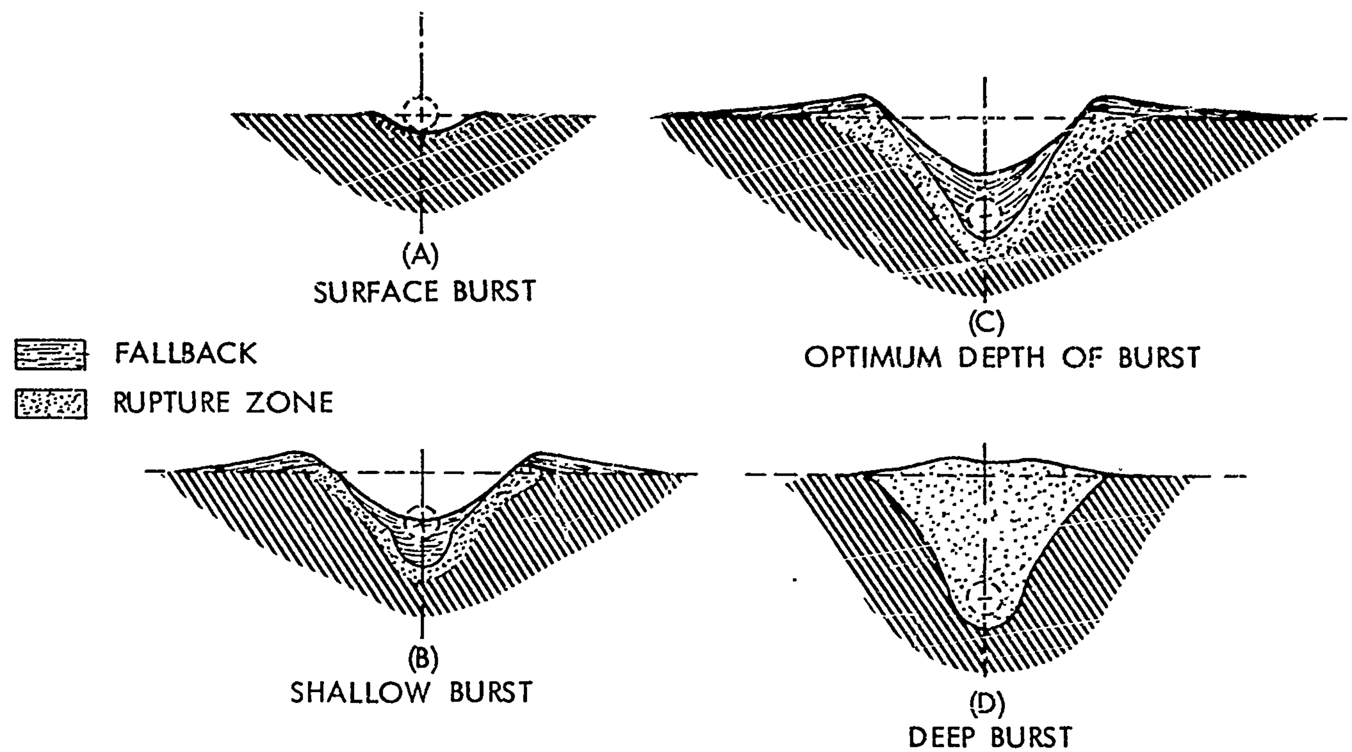


FIG. 3. CRATER PROFILES VS DEPTH OF BURST IN ROCK (FROM HUGHES, 27)

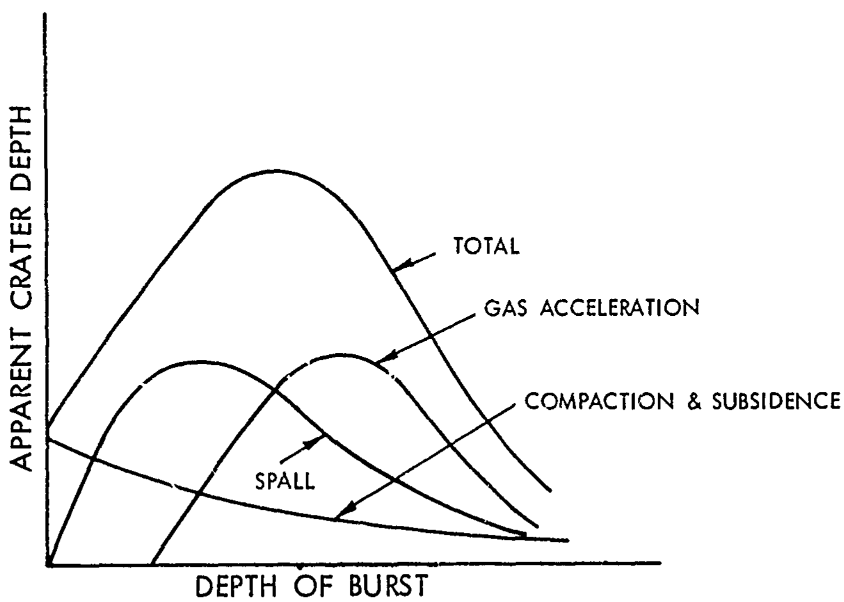


FIG. 4. ESTIMATED RELATIVE CONTRIBUTION OF THE VARIOUS MECHANISMS TO APPARENT CRATER DEPTH (FROM NORDYKE, 76)

SECTION III

REVIEW OF PREVIOUS CRATERING RESEARCH

There have been thousands of cratering experiments and hundreds of technical reports, articles, and books written as a result of these experiments and associated phenomena. Over 300 of these publications were reviewed for this study. This section presents a brief review of cratering experience and analysis. A brief history of recent cratering research and symposiums relating to that research is presented followed by the various prediction techniques available and the information found on the effects of material properties.

Nuclear Cratering Experience (13,45). There have been 10 nuclear detonations at the Nevada Test Site involving four different geologic media in level terrain which resulted in the creation of craters (or a mound as in the case of Sulky) which are considered applicable to explosive excavation. These detonations are listed as the first 10 events in Appendix I. Yields for these events varied from 0.42 kiloton for Danny Boy to 100 kilotons for Sedan (one kiloton = 1,000 tons equivalent weight of TNT).

High-Explosive Cratering Experience. Good summaries of past research in this area can be found in references 46, 81 and 87. Lists for the majority of the experiments can be found in references 15, 60 and 87. In all, these experiments number

in the thousands and involve more than 20 different soil and rock materials. They range in yield from 1 gram to 1 million pounds of TNT and include the full range of depths of burst. Considering each material, the largest number of these experiments were performed in a lightly cemented sand-gravel mixture known as desert alluvium. The number of experiments applicable for this research was considerably less than the total number available. For instance, original plans had included the Dugway cratering series in limestone, granite,and sandstone (76). Later review, however, determined that the crater dimensions reported were not those for the apparent crater as had been indicated by Vortman (87), but were mucked dimensions; i.e., all loose rubble in the crater was removed before crater dimensions were measured. Crater dimensions for this series, therefore, lie somewhere between apparent and true crater definitions. It was also necessary to eliminate hundreds of experiments reported by Sager (60) because other than spherical charges were used and because very few of the experimentors had reported material properties. A good conclusion that can be made regarding the various experiments and their data plots is that the data are highly scattered because explosive experiments in natural materials are difficult to control. The high-explosive experiments used in this research are shown in Appendix I beginning with event 9.

<u>Symposiums Related to Cratering</u>. The Plowshare Program

(the peaceful uses of nuclear explosives) was formally established in 1957 (30). At about the same time, the first contained nuclear experiment, Ranier, was executed (31). Ranier was a 1.7-kiloton explosion 900 feet below the surface. Because of the success of the Ranier event, numerous speculations were made as to the uses of underground explosions. The general range of ideas was first reported publicly in 1958 at the Atoms for Peace Conference in Geneva. This later became the First Plowshare Symposium. In 1959, the Second Plowshare Symposium was held in San Francisco and initial presentations on the uses of nuclear explosives for excavation and extrapolation of chemical explosive data for possible nuclear explosive application were presented (54).

In 1961, a Geophysical Laboratory - Lawrence Radiation Cratering Symposium was held in Washington D.C. (44). This was really the first somewhat all inclusive up-to-date presentation relative to cratering data and phenomena. Scaling laws, empirical analysis, theoretical calculations, nuclear cratering to-date, and explosive craters in desert alluvium, tuff and basalt were some of the more pertinent subjects presented. Nordyke presented his preliminary theory for the mechanics of crater formation; this theory is still being followed today.

In 1964, the Third Plowshare Symposium with its theme "Engineering with Nuclear Explosives" was held at the University of California, Davis Campus (74). Over 30 presentations were

made that offered an up-to-date picture for using nuclear explosives for engineering purposes. By this time additional nuclear cratering data, including the 100-kiloton Sedan event, were available. Knox and Terhune (32) presented results obtained from using SOC, the two-dimensional computer model of cratering physics during the gas acceleration phase. A good portion of the data presented at the conference was later used by Teller (70) to write the book The Constructive Uses of Nuclear Weapons.

In January 1970, the most recent symposium, Engineering with Nuclear Explosives, was held in Las Vegas, Nevada (55). Over 100 presentations were made of which 17 were directly related to excavation. Since a number of the presentations relate to this research, they are discussed in the next two subsections.

Prediction Techniques and Scaling. To date there are basically two approaches being used for predicting crater dimensions. The first involves computer calculations of the mound and cavity growth used in conjunction with a free-fall, throw out model which gives an estimate of the crater radius and ejecta boundary. The second basic approach uses empirical scaling relationships. Another approach, although not so widely used but which deserves mentioning, is a quasi-static approach which considers cratering as an earth pressure problem.

SOC (spherical symmetry, one dimensional) and TENSOR

(cylindrical symmetry, two dimensional) computer codes numerically describe the propagation of a stress wave of arbitrary amplitude through a medium (6,12,32,36,37,71). These codes are hydrodynamic Lagrangian finite-difference approximations of the equation of motion which describe the behavior of a medium subjected to a stress tensor in one (SOC) and two (TENSOR) space dimensions. The code calculations handle both the initial shock wave phase, which creates spall velocities and the gas acceleration phase. The end product of the TENSOR code calculations is a chronological history of the cavity and mound growth resulting from an underground explosive detonation. The code calculations runs until the particle velocities no longer increase significantly from cycle to cycle. At this point, a free-fall throw out model calculation is used to determine the mode of deposition of that material which has been given sufficient velocity to pass the original ground surface. The ballistic trajectory of any given mass determines its final position on the surface. The throw out model calculation permits one to estimate crater radius and the maximum range to which significant material is thrown by the detonation. An estimate of the crater depth may also be made by considering the stability of the cavity walls and the bulking characteristics of the material which falls back into the crater opening. Since these codes assume that the material behaves hydrodynamically not only in the melted region but in the consolidated and

cracked regions of the media, extensive laboratory testing is required to develop pressure-volume relationships for the material involved. The big advantage to this method is that it provides a visual graphical representation of the mound and cavity growth and fall-back. The disadvantages are that it requires an enormous amount of computer time to accomplish the computation and it requires extensive material testing to obtain pressure-volume relationships, rigidity modulus, tensile strength and distortional energy limits. Failure in the material is assumed to occur either when the tensile strength is exceeded or when maximum distortional strain energy is reached.

The second crater geometry prediction approach involves the use of scaling laws which relate crater dimensions from some reference yield to crater dimensions for any energy yield. The preponderance of cratering research (8,10,11,15,46,61,77,88) has been concerned with or utilized this prediction approach. This procedure in its simplest form is based on an empirical determination of the scaling exponent, m, as a function of soil type, using the assumed relationships

$$R = C_1W^{1/m};\ D = C_2W^{1/m};\ V = C_3W^{1/m} \quad \ldots\ldots \quad (1)$$

where R, D and W are the radius, depth and volume, respectively, of the crater, C_i are constants related to the soil type and depth of burst and W is the energy release. If a dimensional

analysis is made, it would appear that m should be 3 for radius and depth and 1 for the volume if the effects of gravity and material friction are omitted; however when gravity of the material is considered, m becomes 4 for radius and depth and 4/3 for volume. The results of cratering experiments to date, however, have led to the development of m = 3.4 for radius and depth and m = 3.4/3 for volume. Although this relationship is very simple, the only way C_i can be determined is by performing a series of cratering experiments for the material in question. There is considerable actual data scatter, however, compared with the smooth curve this technique produces. The constants, C_i, therefore,appear to be variables which depends on material properties. At best, then, these relationships provide only a very rough estimate of cratering dimensions since all material properties are ignored.

A third method for predicting crater dimensions considers cratering as an earth pressure problem (42,78,79,80,81). This method considers expansion of the explosive cavity to some ultimate radius and pressure, at which time equilibrium is assumed to exist, at least for a while. For the cratered medium, it is assumed that a part of it, adjacent to the cavity, behaves as a rigid plastic solid, defined by a Mohr's envelop for the material. At a sufficient distance from the explosive charge the medium is assumed to behave as a linearly deformable, isotropic solid defined by a deformation modulus and a Poisson's

ratio. This method appears very reasonable, however it has only been applied to very small scale laboratory experiments. In addition, it does not consider surface spallation and does not seem to apply for surface bursts.

Material Property Effects. Although numerous observations and studies of cratering for both conventional and nuclear explosives have led to a fair understanding of the basic processes and phenomena involved,the physical characteristics of the cratering medium which significantly influence crater sizes and shapes were found to be largely unknown.

Whitman (89) postulated that crater dimensions were primarily related to soil type through the soil's shearing resistance. His study developed trends between crater size and soil strength for the weaker soils, but trends for the stronger soils and rocks were quite obscure.

Based on limited data, Baker (1) was able to relate material seismic velocity, angle of shearing resistance for sands, tensile strength for rocks,and relative consistency of clay to a radius modulus developed by Saxe (62) to relate a scaled normalized radius and the scaled depth of burial.

Chabai (11) made a dimensional analysis of scaling dimensions of craters and considered the following medium properties as being sufficient to describe the phenomena of cratering: density of undisturbed medium, yield strength of the medium, a viscosity or dissipation variable of the medium

and the sonic velocity in the medium.

Westine (88) considered dimensional analysis and developed the following relationship:

$$R_a/Dob = f[W^{7/24}/(\rho^{7/24}\ g^{1/8}\ c^{1/3}\ Dob)] \quad . . . . (2)$$

in which ρ = mass unit weight, g = acceleration due to gravity and c = seismic velocity. Westine's plots of the data from five different materials show some reduction of the data scatter using his technique. The disadvantage in using this approach is that it implicitly assumes that an increase in unit weight and seismic velocity will result in a smaller crater dimension.

Terhune (71) listed the following material parameters in the order of their importance for determining the cratering efficiency of the medium: (1) Water content; (2) shear strength; (3) porosity (compactibility); and (4) compressibility. He stressed the point that an increase in water content decreases the compressibility, drastically reduces the shear strength and provides an additional energy source in the form of a non-condensable gas.

SECTION IV

PURPOSE, SCOPE, AND PROCEDURE

The purpose of this research was to evaluate the data from published cratering experiments in an effort to show the effect of soil and rock properties on crater dimensions in conjunction with the burial depth and energy of the explosive charge. A secondary purpose was to show that no real analysis can ever be made of cratering data until controlled experiments are conducted or unless soil and rock property measurements are carefully made throughout the material field.

Of the thousands of cratering experiments that have been conducted, only a little more than 200 tests were selected for analysis. The remaining tests did not meet the general criteria established for this study. From the tests selected, those where the charge was detonated above the surface or the depth of burial was so great that a mound or slight depression developed, instead of a crater, were not used in the analysis.

The procedure used to accomplish the research was statistical analysis of data from existing cratering experiments. This involved the following: cataloging all crater and related material property data; selecting a proper regression model to develop empirical equations for apparent crater radius, depth and volume in terms of explosive weight and depth of burst for specific materials; integration of the various material properties

into the model to develop the best equations for all the materials combined; and analyzing the best equations to determine the specific effect of the material properties used. An inherent part of the procedure was the development and use of computer programs.

SECTION V

EXPERIMENTAL DATA

This section presents the method and approach used to acquire and catalog the experimental crater and associated material property data necessary for this study. The cataloged listing is referred to and discussed in some detail. Sorting of the data to allow for better comparison and analysis is briefly described.

Data Acquisition. Using the Corps of Engineers' "Compendium of Crater Data" (60), Vortman's "Ten Years of High Explosive Cratering Research at Sandia Laboratory" (87), and Circeo's "Nuclear Excavation: Review and Analysis" (13), as guides to previously conducted experiments, the original source documents were obtained and reviewed. This involved making visits to Sandia Laboratory and Air Force Weapons Lab, Albuquerque, N.M. and to Lawrence Radiation Laboratory and U. S. Army Engineer Nuclear Cratering Group, Livermore, California.

A review of the literature showed that there was a wide variation in the experiments as well as a wide variation in the parameters measured. The following criteria was established to determine if a particular cratering experiment was to be cataloged and used in this analysis:

1. The explosive charge had to be single and spherical with a TNT equivalent weight of at least 1 pound.

2. The dimensions measured had to be for the apparent crater.
3. The experimental terrain had to be reasonably level.
4. Sufficient material properties had to be measured or it had to be possible to estimate them with some degree of confidence from other recorded data.

Although crater dimensions were obtained for the various experiments with relative ease, soil and rock properties presented a very perplexing problem. For a number of the nuclear events, extensive soil borings and tests were reported. In other cases, only one soil test pit and limited testing was reported for a complete series of experiments. Somewhat arbitrarily, but keeping in mind the cratering phenomenology involved, those material properties which were thought to effect crater geometry were selected to be cataloged.

Data Cataloging. By considering all the data required to properly catalog each cratering event, formats and programs for computer input and output were developed. Every effort was made to keep the data for a particular cratering event to a minimum but yet make the data as complete as possible. For example, cataloging only the grain specific gravity, dry unit weight and moisture content of the media for a particular event allowed for computer calculation of various parameters such as total unit weight, degree of saturation, porosity, percent air, void ratio, etc. Data input to the computer was made to

serve a dual purpose. It was used to produce the cataloged listing of crater data and as a basic data source for the analysis.

The listing of all data cataloged for this research is included in Appendix I. This appendix is divided into the following four segments:

1. A list of all notation and definitions associated with the cataloged data.
2. The computer output crater data list.
3. The two line computer listing of all the cataloged material property data associated with the crater data list.
4. The notes referred to in both the crater data and material property data listings.

It was initially thought that there existed many more measurements of cratering event material property data. In the final analysis, sufficient data was just not available to obtain measured values for each and every event or in most cases even for a series of events. Estimated values dominate the material property data section of the cataloged data. To differentiate, estimated values are indicated by a dollar sign in the data listing.

Viewing the crater data list, it can be seen that the approximate energy of the nuclear explosive cratering events was only estimated within 20 percent. This was due, apparently,

to the unsureness of the amount of nuclear material which actually participated in the reaction. As discussed by Vortman (87) for most high explosive events, cast spherical charges of TNT detonated at their centers were used for yields of 1000 pounds or less. For charges larger than 1000 pounds, cast blocks of TNT were stacked to approximate a sphere. For certain experiments liquid nitromethane was used. The liquid was placed in a spun aluminum sphere or in a mined cavity lined with an impervious material. For a number of the very small explosive tests, Military C-4 explosive was used. Equivalent weight of TNT factors for these latter explosives was based on the heat of detonation as reflected in Cook (14). There is, however, some question as to whether these equivalency factors are completely valid. There seems to be an optimum rate of burning for an explosive for a particular depth of burst in a particular material which will produce the largest crater. It is felt, however, that the equivalent weight of TNT shown in the crater data list for all events except the nuclear tests is within five percent.

Depending on the method used by the original investigators to measure crater dimensions, these dimensions are considered accurate only to within five percent. Again as discussed by Vortman (87), crater measurements have been determined using various techniques. These techniques have consisted of almost everything imaginable from conventional ground surveys to the

use of adjustable rods to aerial mapping. Lip heights and slope angles shown in the listing (although not specifically used in this research) were not reported by many of the investigators. Values reported, in many cases, reflect values measured from typical cross sections.

Material property values reported in the material property data list reflect those which were either reported by the investigator as an average for the experiment or series of experiments, or where possible, taken from boring logs and associated tests. In the latter case, a weighted average for a particular material property was computed for the vertical column in question. These weighted averages for the various borings were then interpolated or extrapolated to obtain the values reported for the explosive event location. Although the material property data list contains predominately estimated values, the majority of these estimated values were extrapolated from experiments in like or similar materials. It would have been advantageous to have been able to obtain specific measured values for each event. Where measured, material property values are considered accurate only to within 10 percent. Where values are estimated, it is believed that they are within 20 percent.

Data Sorting. To allow for better comparison and analysis of the data cataloged, a computer subroutine was written and used. This subroutine provided for sorting on any three

specified parameters at one time. The sorting scheme that was found to be most useful aligned the data by type of material, then by scaled depth of burst and lastly by explosive weight.

SECTION VI

EMPIRICAL DATA ANALYSIS

This section describes the regression analysis technique used to develop a functional relationship between crater dimensions and explosive charge weight and depth of burst for a given soil or rock type. It also discusses the function constants obtained, presents plots of the actual data and presents the resultant regression curves to predict crater dimensions for nine groupings of the data.

Regression Analysis (16,39). The data for this research were analyzed and the prediction formulas for crater dimensions were developed using applied regression analysis. First, the dependent variable (the variable for which prediction was desired) was selected and the independent variables (the parameters thought to have some influence on the dependent variable) were assumed. Next a form of the answer (the model) was assumed and the data applied to the model to obtain its coefficients. This was accomplished through the method of least squares surface fitting, whereby the sum of squares of the distances between the assumed surface and the actual data points was minimized. If the sum of squares is a minimum and the coefficients of the assumed model are determined, then this is the best fitting surface for the model and data used. Lastly through computation of a multiple correlation coefficient and

by an examination of the least squares residuals the prediction formula was evaluated.

Regression analysis has become a fairly common tool for analyzing experimental data and developing function relationships for that data. For this reason, it seems sufficient to mention only that an enormous amount of mathematical computation, including the solution of a large number of simultaneous equations, is required. Only through the use of a high-speed computer is this possible.

The computer program used was specifically written for this research. Although library regression analysis programs were available, it was felt that these programs were too elaborate and did not provide the flexibility needed for this research. The computer program written was intended to be a very flexible, minimum essential program that would adequately accomplish the data cataloging and sorting, the least squares surface fit and the evaluation of the fit. The multiple linear regression portions of the program were written using statistics books as guides (16,24). The matrix inversion, multiplication and print subroutines were available from previous research (75) and were modified for use here. As the research progressed, numerous changes, additions and deletions were made based on the scheme, procedure or purpose being tried at the moment. The program was originally written for the IBM 360/65 computer, but was later revised for use on the CDC 6600. Appendix II

contains a brief description of the program and its essential features along with a typical print-out of the essential portions of the program and its output after being run on the CDC 6600.

Regression Approaches Considered and Tried. The number of regression approaches considered and tried was so numerous, it is superfluous to list them all. At the beginning, regressions of radius, depth, or volume as a linear function of depth of burst, explosive weight and various material properties were attempted. A second approach considered a linear crater dimension to be a function of various dimensionless parameters taken from Chabai's work (11). An attempt was also made to consider all material parameters which would reflect the amount of energy being dissipated during the cratering process. A closely related approach was to consider those material properties which would relate to the mechanisms of compaction, subsidence, spall and gas acceleration as proposed by Nordyke (46). In all of the above cases, sufficient material properties were not available to include all applicable terms thought to be important. An attempt was made to use available and applicable material parameters in a linear fit, but to no avail. When one considered a second order regression model, the number of parameters to be used suddenly becomes excessive for the data available and for the basic research purpose.

Of special note was the attempt to use Westine's technique

(88). Regression using this approach produced a high multiple correlation ratio. However, the residuals between the estimated and actual values of the dependent variables were found to be excessive. This was particularly true for the range of data where R_a/Dob was less than 2.

Regression Model Used. After much deliberation and due consideration of the literature reviewed, it was felt that the better approach for the solution of crater dimensions for one particular media was to consider a scaled linear crater dimension as a function of the scaled depth of burst. Although there seemed to be some question as to the proper scaling to use, the scaling exponent which appeared to most recently be used and justified was 7/24. This figure is the average of conventional cube root scaling (gravity effects excluded) and fourth root scaling (gravity effects included). The scaling exponent eventually used was 5/16 and resulted from a special study of the data cataloged for this research. The next question which arose was what model should be used for regression? After studying plots of the scaled data and after considering what happens to crater size as the depth of burst (or height of burst) is varied from one extreme to the other it became obvious that a curve reflecting the final dimension of a crater when plotted as a function of depth of burst (and height of burst) should be asymptotic at both extremes and reach its maximum value at the optimum depth of burst. This suggested the bell shaped curve

with its inherent advantages and disadvantages which will be discussed later. Using this approach, the regression suddenly improved for any one particular cratering media.

The general form of a bell curve is as follows:

$$y = B_1 \exp [B_2 (x+B_3)^2] \quad . \ . \ . \ . \ . \ . \ (3)$$

That of the skewed bell curve used took the following form:

$$y = B_1 \exp [B_2 (x+B_3)(x+B_4)^2] \quad . \ . \ . \ . \ . \ (4)$$

in which x = the scaled depth of burst ($Dob/W^{5/16}$) and where y = the scaled linear apparent crater dimension being considered: (1) Radius ($R_a/W^{5/16}$); (2) depth ($D_a/W^{5/16}$); or (3) cube root of volume ($V_a^{1/3}/W^{5/16}$). A big advantage to these curves is that B_1 is the maximum height of the curve and it occurs along the abscissa at $-B_3$ for the standard curve and at $-B_4$ for the skewed form. In other words if y is equal to the scaled radius for the first case, then the maximum scaled radius is B_1, and it occurs at an optimum scaled depth of burst of $-B_3$. B_2 sets the rate of change of the slope away from the (B_3, B_1) point. The $(x+B_3)$ term in the second case allows for skewing the standard bell curve. As can be seen, this introduces a second root to the equation. In the majority of surface fitting cases, this posed no problem since the second root and associated slope change were outside the range of the data. Where the data was minimal and somewhat scattered, using the skewed bell curve proved infeasible.

Since the above curves are not applicable to multiple linear regression, they were used in the following coded forms. For the standard bell curve:

$$\ln y = A_1 + A_2 x + A_3 x^2 \quad . . . . . . (5)$$

where $A_1 = \ln B_1 + B_2 B_3^2$, $A_2 = 2B_2 B_3$ and $A_3 = B_2$; or conversely: $B_1 = \exp(A_1 - A_2^2/4A_3)$, $B_2 = A_3$ and $B_3 = A_2/2A_3$. For the skewed bell curve:

$$\ln y = A_1 + A_2 x + A_3 x^2 + A_4 x^3 \quad . . . (6)$$

where $A_1 = \ln B_1 + B_2 B_3 B_4^2$, $A_2 = B_2 B_4 (2B_3 + B_4)$, $A_3 = B_2 (B_3 + 2B_4)$ and $A_4 = B_2$; or conversely $B_2 = A_4$, $B_4 = [A_3/A_4 \pm (A_3^2/A_4^2 - 3A_2/A_4)^{1/2}]/3$, $B_3 = A_3/A_4 - 2B_4$ and $B_1 = \exp(A_1 - B_2 B_3 B_4^2)$

As can be seen for this later case, two sets of values for the constants B_4, B_3 and B_1 are obtained. Examination of the numerical values obtained for a particular curve fit, however, quickly show the correct set to be used.

Determination of Best Scaling Exponent. For all the initial surface fits made, 1/4, 7/24 and 1/3 were used as the scaling exponents. For every set of data except one, 7/24 was found to produce the best fit of the data. Where the data consisted of a large amount of surface bursts, 1/3 was found to produce the best fit. This suggested using a variable exponent as a function of depth of burst. Numerous computer runs were made attempting to use an exponent which was a

function of depth of burst or an initial scaled depth of burst. Although a better fit was obtained for surface burst data, the over-all fit was never as good as that obtained from just using 7/24. Vortman (84) showed that the scaling exponent for surface bursts could vary from low of 0.23 for depth to 0.44 for radius depending on the material in question.

A special computer run was made to vary the scaling exponent from a value of 0.29 to 0.35. It was found that a scaling exponent of 0.31 produced the best fits for radius and cube root of volume while 0.32 produced the best fit for depth (there was very little difference, however, between the fits obtained from using 0.31 and 0.32). It was decided to use 5/16 (or 0.3125) as the scaling exponent for the remainder of the research. This figure represents the average of the 7/24 and 1/3 figures which have been used so predominately by other investigators.

Equations and Data Plots for Specific Materials. Using equations (3) and (4) as the regression models (the standard bell curve and the skewed bell curve), the coefficients (B values) were generated to obtain the best fit of the data to empirically predict the scaled depth, radius or cube root of volume. This was accomplished for each of eight groups of material (or experiment) data and in addition for all the data combined. Linear dimensions used in these equations were in feet while W was in pounds of TNT. Listed in Table 1 are the B values

TABLE 1. EQUATION COEFFICIENTS FOR VARIOUS MATERIALS

Material	Crater Dimension	Associated Bell Curve Coefficients B_1	B_2	B_3	B_4	Multiple Correlation Coefficient	% of Data Predicted Within ±10%
Clay Shale	R_a	3.500	5.942	-2.737	-1.581	101.2	25.0
	D_a	1.482	4.229	-2.898	-1.538	97.2	12.5
	$V_a^{1/3}$	2.817	5.715	-2.783	-1.576	101.4	25.0
Desert Alluvium	R_a	2.447	-0.217	-1.820		95.8	60.0
	D_a	1.234	0.092	-7.315	-1.352	95.7	28.0
	$V_a^{1/3}$	2.098	0.030	-10.605	-1.622	95.1	60.0
Sand	R_a	2.456	-0.438	-1.186		99.4	93.8
	D_a	1.809	-0.720	1.151	-1.260	99.3	59.4
	$V_a^{1/3}$	2.475	0.181	3.222	-1.213	99.0	78.1
Basalt	R_a	1.955	-0.495	-1.290		97.4	57.9
	D_a	1.023	-0.789	-1.266		97.5	52.6
	$V_a^{1/3}$	1.710	-0.564	-1.270		97.6	47.4
Alluvium (Zulu Series)	R_a	2.271	-0.050	-2.348		98.8	90.0
	D_a	1.143	-0.062	-1.774		95.2	45.0
	$V_a^{1/3}$	2.020	-0.053	-2.144		97.5	85.0

TABLE 1. EQUATION COEFFICIENTS FOR VARIOUS MATERIALS (Continued)

Material	Crater Dimension	Associated Bell Curve Coefficients				Multiple Correlation Coefficient	% of Data Predicted Within ±10%
		B_1	B_2	B_3	B_4		
Various Rocks	R_a	2.248	-0.802	-1.040		82.6	22.2
	D_a	0.857	-0.748	-1.114		88.2	33.3
	$V_a^{1/3}$	1.772	-0.771	-1.052		89.7	22.2
Playa (Air Vent Series)	R_a	1.907	-0.272	-1.474		98.2	70.8
	D_a	0.829	-0.726	-0.879		99.3	66.7
	$V_a^{1/3}$	1.489	-0.442	-1.090		98.5	66.7
Playa (Toboggan Series)	R_a	1.978	-0.710	-1.151		98.0	59.1
	D_a	1.033	-1.608	-0.816		99.1	45.4
	$V_a^{1/3}$	1.689	-0.925	-1.009		98.7	63.6
All Data Combined	R_a	2.136	-0.201	-1.817		87.8	37.5
	D_a	1.057	0.109	-6.325	-1.173	84.6	22.3
	$V_a^{1/3}$	1.837	0.058	-6.618	-1.403	85.1	32.1

obtained. The number of B values listed for a particular crater dimension for a particular material reflects which equation produced the best fit. Actual plots of the data used and the resultant empirical curves obtained are included as Appendix III.

A study of these data plots reveals several interesting facts. The smallest craters were produced in playa, the lighter weight, weaker material; next came the rocks, alluvium and sand; and lastly the largest craters were produced in the clay shale. The exact order for the different materials changes somewhat depending upon which crater dimension is being considered. A second important fact that can be noted is that in almost every case, nuclear events produced smaller scaled craters than their high-explosive counterparts in the same material. If attention is brought to bear on the surface burst data for the Air Vent Series, which also included the two 20 ton Flat Top events, it becomes obvious that a larger scaling factor would reduce the data scatter considerably. When this fact is considered along with a close look at other surface burst data, it would appear that surface and near surface bursts should be studied separately and should possibly have been eliminated from the data used in this research.

Discussion of Approach Used. Since a good portion of the time spent on this research was in regression analysis, it seems appropriate to discuss this process and its applicability to

research of this type. In general, it is sufficient to say that multiple regression analysis for such a complicated problem as was encountered here is more of an art than a scientific approach. For regression analysis to be of real benefit, experience with its application and at least some knowledge of how the dependent variable behaves as a function of the various independent variables is highly desired. Otherwise, it becomes the problem instead of a tool to help solve the real problem. Statistics books, in general, tend to oversimplify the process (rightfully so if they are to teach the principles involved) but the real world just does not seem to be composed of only one or two independent variables. If a general series is assumed as the regression model, a very few variables, applied to say a fourth order fit, produces an excessive number of terms to be evaluated. This number of terms can quickly exceed the number of the observations or make it extremely difficult to obtain an accurate solution of the normal equations even using the computer. It is only when the behavior can be simply explained or when reasonably precise laws govern the behavior that regression analysis can be used with the assurance of gratifying results.

Even though the idea of using the bell curve as the regression model was the key to any success achieved in this research, it did not, of course, fit all the data well. Several methods were tried in an attempt to skew this model to improve

the data fit, however each method had its inherent problems. Although the method chosen works satisfactorily, it no longer is a bell curve. It is asymptotic to the x-axis on only one end. If this end falls toward the deeper depth of burst portion of the graph then no real problem exists provided the "S" portion of the curve does not situate itself in the middle of the data as can be seen for the clay shale plots in Appendix III. Extreme care, therefore, must be taken when using this model to insure that the proper portion of the curve, did in fact, fit the data points provided.

As can be noted from the results of the surface fits, the standard bell curve fitted more of the data as well or better than the skewed form. It also, in general, produced a better fit for scaled radius data than it did for scaled depth and scaled cube root of volume data. If the assumption is made that the bell curve is truly representative of true crater dimensions, then this fact makes sense. The apparent crater radius is essentially equal to the true radius from depths of burst ranging from zero to past optimum. It is only at the deeper depths of burst that these two radii diverge. Of the three crater dimensions, poorer fits were obtained for apparent crater depth. Fall back is the important factor here, the volume (and in turn the height) of the fall back being dependent on bulking and other material characteristics. Judging from the data scatter, material properties are very critical for this

particular crater dimension. Judging also from the data plots, there exists a range of deep depths of burst in the explosion process where the material either responds or does not respond too well to being thrown out.

Obviously, from the above discussion, material properties are important in determination of crater size. Their inclusion into the bell curve prediction scheme is covered next.

SECTION VII

MATERIAL EFFECTS

This section describes the method used to incorporate soil and rock properties into the bell curve regression models, the resulting general equations obtained and the analysis of these equations to determine specific material property effects. It also includes a discussion of material properties in general and of the material properties used in this research in particular. Lastly, it presents a brief discussion of the relationship between material properties and cratering mechanics.

Incorporation of Material Properties. After normalizing the crater dimensions and after determining that the bell curve was an appropriate regression model to use if material property effects were ignored, it was surmised that the position of the bell curve (i.e., the height, point of zero slope, etc.) was a function of the media material properties. In other words, the bell curve regression coefficients obtained for the various materials are really a function of appropriate material properties. This led to regression analysis involving inclusion of soil and rock properties.

Ideally, if sufficient data had been available at various material property conditions, then each coefficient (B value) of the bell curve could have been expressed as a function of these conditions. However, to make full use of the data, it was

necessary to assume that the coefficients of the coded bell curve, the A values, were functions of material properties. The B values are, of course, related to the A values as described by equations (5) and (6), but when the B values are shown in terms of material parameters, the resulting equation is so involved that it becomes meaningless. It was quickly determined that the coded bell curve constants were not linear functions of any one or more material properties. Reasonable regression began to occur when second order and interaction terms were included. This, however, reduced the number of material properties which could be considered at one time without increasing the number of parameters being used. Every effort was made throughout the research to keep the number of parameters to 40 or less. In the final analysis, the best prediction formulas were obtained using either equation (5) or (6) and the following functional relationships for their coefficients:

$$A_1 = C_1 + C_2\,\gamma^{5/16} + C_3\,S + C_4\,M + C_5\,\gamma^{5/8} + C_6\,E_v + C_7\,M^2 + C_8\,\gamma^{5/16}\,S + C_9\,\gamma^{5/16}\,M + C_{10}\,SM \tag{7a}$$

$$A_2 = C_{11} + C_{12}\,\gamma^{5/16} + \ldots + C_{20}\,SM \tag{7b}$$

$$A_3 = C_{21} + C_{22}\,\gamma^{5/16} + \ldots + C_{30}\,SM \tag{7c}$$

$$A_4 = C_{31} + C_{32}\,\gamma^{5/16} + \ldots + C_{40}\,SM \tag{7d}$$

in which γ = total unit weight of the material, in grams per cubic centimeter; S = degree of saturation, ranging from zero

to 1.0; E_V = vaporization energy of the material, in thousands of pounds per square inch per cubic inch (this factor is zero for all except the nuclear events); and where M may equal any one of the following: (1) G_s, the grain bulk specific gravity; (2) tan ϕ, the material's shearing resistance; or (3) $c^{1/3}$, the seismic velocity of the material, in feet per second.

Appendix IV contains the equation coefficients (C values) for the various crater dimensions and combinations of material properties. Numerous computer runs were made to determine which material properties correlated best with crater dimensions and produced the best surface fit. As could be expected, those material properties which were predominately measured values correlated the best and these included the dry unit weight and moisture content and to a lesser degree the shearing resistance. Dimensional analyses by Westine (88) and Saxe (61) suggested the use of $Y^{5/16}$ and $c^{1/3}$. These scaled values produced better regression than when their full values were used. Degree of saturation, S, and specific gravity, G_s, were selected after trying other related factors such as porosity, percent air and void ratio. They appeared to correlate better and have a little more meaning when considering their effect on crater dimensions.

The vaporization energy of the material, E_V, was used primarily to differentiate between nuclear and high explosive events. From actual experience (45) it was known that nuclear events produced smaller craters than would be predicted by

scaling from high explosive cratering events. This fact became evident when the nuclear events were analyzed with and without the E_v term as a parameter. To keep the number of parameters to a minimum, E_v was used in place of the normally expected S^2 term in the second order material property scheme utilized. The S^2 term was found to have the least effect of all the nine material property terms on the scaled crater dimension.

Also an attempt was made to incorporate all the material parameters used into one 40 parameter equation, by considering the terms in previous surface fits which had the least effect on the dependent variable. This attempt, however, did not produce as good a surface fit as when only four material properties were used.

When this research was first undertaken, it was hoped that crater dimensions for at least 90 percent of the events could be predicted within ± 10 percent. After viewing the accuracy of the basic cataloged data, a goal of 80 percent of the events to be predicted within ± 20 percent was established. This second goal was more than met for radius and volume but not quite met for predicting depth. The final figures obtained do give, however, some indication as to the reliance of using material properties to predict crater dimensions and provide some validity to the assumption that investigation of the general equations obtained would allow a determination of the effect of soil and rock properties on crater dimensions.

Although an attempt was made to go back over the data to try and find specific explanations as to why specific events did not predict well, very little success was obtained. In general, it appeared that the accuracy of material property inputs was the predominate reason. Not using a better scaling factor for the surface bursts accounted for a small amount of discrepancy. Even Palanquin (a nuclear test) (82) which did not produce the crater expected and which in turn was blamed on a stemming failure, predicted well. The general equations using $\gamma^{5/16}$, S, G_s and E_v predicted Palanquin's radius and volume only eight and five percents higher respectively than those which occurred and actually predicted the depth 5 percent lower than the actual.

How well will the general equations obtained for the various crater dimensions predict future events? Judging from the data observed, there is an 85 percent chance of being within ± 15 percent for materials that fall within the range of the ones used in this research and for a scaled depth of burst less than 2.

Effects of Material Properties. After development of the general equations for crater dimensions, parametric studies of these equations were made to determine how crater geometry was effected as the various material properties were varied over their normally expected ranges. This was accomplished by writing a second, but much smaller computer program, to vary

the parameters in the final prediction equations to determine their effect on final crater geometry. Basically, this program read in the constants obtained for the prediction equations, varied the material parameters and scaled depth of burst within their expected ranges and computed the estimated values for scaled radius, depth, or cube root of volume. Since these studies produced pages and pages of computer output, only representative results are included here. These results are graphically presented in Appendix V.

Material Property Definition. Because the results and conclusions regarding the material properties used in this research are presented next, it seems appropriate to discuss just what is a "material property?" The term "material property" appears to have many meanings. These meanings, as they apply to engineering problems, can be catagorized into three areas: (1) Basic, (2) material test, and (3) theoretical.

Basic or primitive material properties are those that relate mass and volume. Examples for a single phase material are: (1) Density, (2) specific volume and (3) specific gravity. For a three phase material mixture, such as soil, where mineral particles comprise the solid phase and where water and air occupy the voids between the mineral particles, the basic material properties relate not only mass to volume for each phase but relate mass and/or volume of each phase to the total volume or total mass. Examples of such basic properties are:

(1) Dry unit weight; (2) total unit weight; (3) saturated unit weight; (4) moisture content; (5) void ratio; (6) porosity; (7) percent saturation; and (8) percent air voids.

The second major category is material test properties. They are defined operationally. The results of specified and arbitrary tests yield these properties. Examples of such properties are: (1) Unconfined compressive strength; (2) Atterberg limits for soils; (3) splitting tensile strength for rock; (4) compressive strength of concrete at 28 days; and (5) Hveen stability of bituminous concrete. Such tests as these are usually standardized.

There may be some logic behind those test procedures that in some way model a mechanics problem, but in essence these test properties are empirical and arbitrary and may not relate at all to the mechanical behavior of the material in other situations. If they do, it is indeed fortunate and a tribute to some investigator's intuitive insight into material behavior.

The third type of material properties depend on a theory of material behavior that relates cause to effect. Usually the cause is stress, or possibly temperature, and the effect, strain or rate of strain. The coefficients in these theoretical relationships are the constitutive constants that describe idealized material behavior. The mathematical model used to describe a material may be as complicated as necessary to cover the range of interest of the material's behavior. Examples of

very simple constitutive equations are those for rigid bodies, perfect fluids, linear elastic solids, perfect gases, and linear viscous fluids. The constants in these equations are called material properties. For example, in linear elastic theory, there are two material properties: the two Lame' constants. More complicated constitutive equations of nonlinear form that relate the stress tensor to the strain tensor and rate of strain tensor have been generated. In the case of plasticity theory, the constants relate the various invariants of the stress tensor at failure. In each of these cases, the theory must exist before a material property is measured. Without the theory, the property does not exist.

It would be ideal and very fortunate if valid relationships existed between the various categories of material properties, however, at best, we are fortunate that properties in one category may be indicative of properties in another.

Material Properties Used in this Research. The best regression equations were obtained as a result of using the total unit weight, the percent saturation, the specific gravity of the grains, the internal shearing resistance and the seismic velocity. Although these parameters may not really be the properties governing material behavior during cratering, they are at least indicators of the properties. None of these parameters except the specific gravity remain constant during the cratering process. They are all functions of the stress

(or strain) level and their initial values are not necessarily indicative of their values during the actual explosive event. However, when used in conjunction with one another and in conjunction with the depth of burst, they provide some indication of the governing material properties. It was interesting, however, to study the effect these indicators did have on crater dimensions.

At the optimum depth of burst for granular materials, larger craters were produced at low and high degress of saturation than were produced at the intermediate values (Figs. 32-34). This was probably because granular materials with low moisture contents have very little cohesion. However, as the moisture content is increased, the material develops some cohesion and therefore greater strength. Whitman (90) showed that cohesion due to pore water increased as the rate of strain increased. The addition of water also increased the weight of the material. When the degree of saturation starts to approach 100 percent, the ability of the material to transmit the shock wave markedly increases. In addition, the strength of the material decreases considerably as the pore water starts to assume more and more of the pressure being exerted on the material. For clays and rocks (Fig. 35), any increase in the degree of saturation appeared to produce larger craters. Additional moisture in these cases did not improve their cohesion but only tended to increase their ability to transmit

the shock wave and to decrease their strength.

Now, if other than optimum depth of burst is considered, the degree of saturation produced slightly different effects (Fig. 32). For deep depths of burst, an increase in the degree of saturation tends to always produce larger craters. For surface bursts, the effect of the degree of saturation was found to be the reverse of that determined for optimum depth of burst. Low- and high-moisture contents produced smaller craters, and there existed an optimum degree of saturation at which the largest crater was obtained. Since compaction is the predominate mechanism here, it follows that materials in this region would behave essentially as they do in normal engineering compaction problems.

Again, considering cratering events at or near optimum depth of burst (Figs. 36 and 37), it was found that the smaller craters resulted from low density and high density materials and that there existed an optimum density at which the largest crater resulted. This feature reflects again that better properties are necessary to predict crater dimensions. If unit mass, strength and the ability of the material to absorb the shock wave are all considered together, then this phenomenon seems plausible. Materials with low weight and strength appear to have high-energy absorption properties whereas dense, high-strength materials do not. Somewhere in the middle, then, there exists a material where these factors do not compliment

each other as much as they do for the two extremes. This density feature appears to hold true for all depths of bursts.

Because the effect of bulk grain specific gravity on crater dimensions is not so meaningful in terms of its application to the effects of material properties, it will only be discussed briefly. A change in grain specific gravity affects the total unit weight and degree of saturation and those were discussed above.

Not so easily explained as the effect of density and degree of saturation on cratering is the effect of the material's internal shearing resistance, tan ϕ. It is very difficult to determine what the actual ranges of tan ϕ are for a particular soil density and degree of saturation. Every effort, then, was made to stay within the area of the actual data to determine the effect of tan ϕ on crater dimensions. In general, it appeared that as tan ϕ increased for soil materials at the lower degrees of saturation and for the rocks, the size of the resultant crater also increased. If high degrees of saturation are considered for the soils, then an increase in tan ϕ decreases the crater size. The only explanation that seems plausible for these effects is to consider the ability of the material to absorb energy in relation to tan ϕ. Apparently the ability of the material to absorb energy increases more with an increase in internal shearing resistance than does the strength for the lower degrees of saturation. At the high degrees of saturation,

however, the energy absorption value apparently levels off and the strength increase is sufficient to produce smaller craters.

Because the parametric study involving tan ϕ appeared to be somewhat meaningless unless values were considered in the same area as the actual data, a parametric study was not performed using the general equation which included seismic velocity. Again it becomes extremely difficult to determine the range of values in seismic velocity which would exist when the density and degree of saturation are assumed. In addition, there were fewer measured values for this parameter and it was included in the general equations with hesitancy. It was felt, however, that even though the data were not the best and this variable is stress dependent, it very likely would give some indication of the material's ability to transmit the shock wave. A cursory review of the data indicates that smaller craters result when the seismic velocity is either low or high and that there exists an optimum value where the largest crater will be produced.

It becomes very difficult to sum up all the possibilities, but in general it appears that for craters produced at or near optimum depth of burst, there exists an optimum unit weight, an optimum internal shearing resistance, an optimum seismic velocity with the degree of saturation at zero percent where the very largest craters will be produced for a particular explosive energy source.

For practical considerations, it appears that the most important of the material indicators used is the degree of saturation (which is of course the result of water content). This study should be helpful in determining whether the addition of water to the medium will either enhance or decrease the size of a crater being considered for the explosive charge weight being used.

Cratering Mechanics and Material Properties. As a result of this analysis of the effects of material properties on crater dimensions, it appears very likely that a reasonably simple cratering theory should be possible. Hopefully the coefficients (material properties) in this theoretical constitutive relationship could be measured using simple laboratory or field techniques. In any case it would appear that these cofficients should in some way be related to the following material properties: (1) Energy dissipation; (2) total unit weight; (3) shear strength; (4) volume change; and (5) moisture.

These five material properties should be measured over the material field for each future test as a minimum material property requirement. The energy dissipation constant should account for the fact that smaller craters result in the lightweight, weaker materials. Unit weight in conjunction with depth of burst would give a measure of the total mass of the material which must overcome gravity. The shear strength constant would account for further energy dissipation. A volume change

constant would account for the change in density of the crater fall back which, in turn, effects the apparent crater depth and volume, Last but not least is the moisture. Vaporiation of moisture surrounding the explosive charge enhances the gas acceleration phase of cratering mechanics. In addition, moisture would modify the effects of all the other four properties proposed.

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

If explosives are to be used for excavation purposes, then predictions of results must incorporate material properties. This study has shown that soil and rock properties are important in determining the size of explosion-produced craters and has provided some insight as to their specific effects. It has shown that previous investigators have been somewhat negligent in measuring material properties for past cratering experiments and that no real analysis of crater data can be made unless the variables are either controlled or measured. This study also has provided a means to predict crater dimensions for any material provided certain soil and rock properties are measured beforehand.

The final general equations obtained will predict the size of 85 percent of the cratering events within ± 15 percent. These equations predict apparent crater radius, depth, and volume in terms of (1) depth of burst, (2) the explosive weight and (3) the following material properties: total unit weight, degree of saturation, grain specific gravity, internal shearing resistance and seismic velocity. For nuclear explosions, the vaporization energy of the material is also included. These equations were developed from data which fell in the following ranges: (1) Explosive charge weights from one pound to 100

kilotons; (2) materials in which the unit weight ranged from 60 to 170 pounds/cubic foot; and (3) charge depths from zero to the point where no crater is produced.

It is not surprising that previous investigators have concluded that the effect of material properties on crater dimensions was somewhat obscure. This is particularly true if only linear and simple curvilinear relationships are considered. It is only when indicative soil and rock properties are considered in conjunction with one another for specific ranges of depths of burst that they become meaningful.

Of the six material properties used in the general equations, percent saturation and total unit weight appeared to be the most important indicators of the effects of material properties. This was due primarily because these two properties were calculated from predominately measured values while those for the other properties used were largely estimated. Prime examples of these effects are as follows: (1) For surface explosions, there exists an optimum percent saturation which will produce the largest crater; (2) for soils and for the explosive charge at optimum depth, zero moisture content produces the largest crater; in this case there is a least favorable percent saturation which will produce the smallest crater; (3) for rock materials and for all materials at deep depths of burst (at least twice the optimum), 100 percent saturation results in the largest crater,and (4) in general, there exists

an optimum unit weight which will produce the largest crater.

The bell curve provides a good model for predicting scaled crater dimensions in terms of scaled depth of burst. Where data indicate nonsymmetry, the skewed form of the bell curve can be used, provided it is done cautiously. The inherent advantage to the bell curve model is that the constants in this model immediately provide the maximum value for the scaled crater dimension under consideration and the optimum scaled depth of burst at which it occurs. This feature makes it useful for practical applications and allows quick comparisons between rock and soil property conditions.

As a result of the knowledge gained in this research effort, the following recommendations are made for future cratering experiments and associated studies:

1. Sufficient material properties should be measured for each and every cratering event. As a minimum, unit weight, moisture content, grain specific gravity, shearing resistance and seismic velocity should be measured. In addition, some measure of energy dissipation and material bulking would be desirable.
2. A method needs to be developed to measure the energy dissipation characteristics for soil and rock in which cratering experiments have and will be performed.

3. A method to measure and evaluate bulking or compaction needs to be developed.
4. A series of laboratory type experiments to consider specifically the effects of percent saturation on crater dimensions would be highly desirable. As a minimum, five levels of the degree of saturation for five levels of depth of burst for a particular dry unit weight would possibly suggest a more accruate relationship between crater dimensions and this very important material parameter.

   This series could also be extended to include a variation in the dry unit weight and the inclusion of various types of materials.
5. For survival of silo-launched missile systems, where the primary interest is in near surface bursts, the surface burst data from this study could be supplemented with additional data and a regression analysis performed. This would allow the scaling exponent, as well as the material constant, to be a function of material properties. Thus, a more accurate prediction of crater dimensions could be obtained for this special case.
6. A simple theory of cratering should be developed using the field equations of mechanics and a material

constitutive equation with sufficient complexity to account for soil or rock failure and energy absorption. Such a constitutive equation should also account for increase in strength as a function of pressure and the thermodynamic properties.

APPENDIX I

CATALOGED CRATER DATA

<u>Notations and Definitions</u>. The following notations and abbreviations are used in the cataloged crater data and material property data listings:

ALLUV - desert alluvium;

ATTBRG LIMITS - Atterberg limits (see also LL and PI) relating to the water content at which soil consistency changes from one state to another, see Wu (91);

B - indicates that there is no value following even though the computer printed zeros;

BULK FACTOR - bulking factor, a ratio of the unit weight of the material in the crater fallback to the preshot unit weight of the material, Frandson (19) analyzed this value for several materials;

CH - inorganic clays of high plasticity;

CNF PRES, PSI - confining pressure at which the confined compressive strength was obtained, in pounds per square inch;

COHESION, PSI - cohesion of the material, in pounds per square inch, based on Mohr-Coulomb failure theory;

CONF COMP, PSI - confined compressive strength of the material, in pounds per square inch, at the particular confining pressure listed in the next column;

CORE RECOV, PRCT - the amount of core recovered during coring operations, in percent; for rock it indicates the material's soundness;

CU FT - cubic feet;

DRY UWT, LBS/CU FT - dry unit weight of the material in pounds per cubic foot;

ELEV, FT - elevation, in feet, which could have been converted to atmospheric pressures which Herr (25) showed to be important;

EQUIV WT, LBS-TNT - equivalent of the explosive charge in pounds of trinitrotoluene;

EVT NO. - event number;

FLE STN, IN/IN - the strain at which failure occurred in either the unconfined or confined compression test, in inches per inch;

FPR MNT - Fort Peck Reservoir, Montana;

FT - feet;

KT - kiloton, one thousand tons equivalent weight of TNT (trinitrotoluene);

LIP HT, FT - apparent crater lip height, in feet;

LL, PR CT - liquid limit (see ATTBRG LIMITS), in percent; the water content of the soil which differentiates between the plastic and liquid consistencies of the soil;

LRL - Lawrence Radiation Laboratory, California;

MELT, MPSI/CIN - the energy required to melt the material, in thousands of pounds per square inch per cubic inch;

ML - inorganic silts and very fine sands, silty or clayey fine sands or clayey silts with slight plasticity;

MOIST, PR CT - moisture content, expressed in percent of the dry unit weight of the material;

MTCE - Multiple Threat Cratering Experiment;

NM - nitromethane;

NTS-A5 - Nevada Test Site Area 5;

NUC - nuclear;

PHI, DEG - the angle of internal shearing resistance, in degrees ,based on Mohr-Coulomb failure theory;

PI, PR CT - plasticity index (see ATTBRG LIMITS), in percent, the water content difference between the liquid limit (LL) and the plastic limit; the plastic limit being that water content of the soil which differentiates between the semisolid and and plastic consistencies of the soil;

POISN RATIO - Poisson's ratio, ratio of the horizontal stress to the vertical stress, which resulted from the theory of elasticity;

PRE-GDLA - Pre-Gondola;

REF NO. - reference number;

RMK, SEE NTE - remarks, see note;

SLP DEG - approximate angle the apparent crater slope makes with the horizontal preshot ground surface;

SM - silty sands, sand-silt mixtures;

SP - poorly graded sands, gravelly sands, little or no fines;

SP GR - bulk specific gravity of soil or rock grains;

TNS - tons;

TNSLE-D, PSI - direct tensile strength of the material, in pounds per square inch;

TNSLE-S, PSI - splitting tensile strength of the material, in pounds per square inch;

UNC COMP, PSI - unconfined compressive strength of the material, in pounds per square inch;

USCS CLASS - the "Unified Soil Classification System" (73);

VAPOR, MPSI/CIN - the energy required to vaporize the material, in thousands of pounds per square inch per cubic inch;

WT-VOL - weight-volume;

YFC WSH - Yakima Firing Center, Washington;

$ - indicates the value following is an estimated value.

Cataloged Crater Data. The crater data cataloged is computer listed in Table 2.

Cataloged Material Property Data. The two line computer listing of the cataloged material property data associated with the cataloged crater data list is presented in Table 3.

Notes. The notes, referred to in either the catalog of crater data or the catalog of associated material properties, follow Table 3.

TABLE 2. CATALOGED CRATER DATA

IDENTIFICATION						EXPLOSIVE DATA			DEPTH OF BURST	APPARENT CRATER DIMENSIONS					RMK
EVT NO.	REF NO.	SERIES/SHOT NAME	SITE	DATE MO YR	MEDIUM	TYPE	YIELD	EQUIV WT LBS-TNT	FT	RADIUS FT	DEPTH FT	VOLUME CU FT	SLP DEG	LIP HT FT	SEE NTE
1	72	SCHOONER	NTS-A20	DEC68	TUFF	NUC	31+-4KT	64000000.00	355.00	426.00	208.00	61637480.00	35	44.00	
2	20	CABRIOLET	NTS-A20	JAN68	RHYOLTE	NUC	2.3+-.5KT	4600000.00	170.75	179.40	116.40	4860675.00	35	31.80	
3	82	PALANQUIN	NTS-A20	APR65	RHYOLTE	NUC	4.3KT	8600000.00	280.00	119.10	78.80	1255977.00	30	21.20	
4	83	SULKY	NTS-A18	DEC64	BASALT	NUC	85+-15TNS	170000.00	90.00	29.10	-9.20	-25400.00	-30 B	0.00	
5	47	SEDAN	NTS-A10	JUL62	ALLUV	NUC	100+-15KT	200000000.00	635.00	608.00	323.00	178200000.00	33	42.60	
6	48	DANNY BOY	NTS-A18	MAR62	BASALT	NUC	.42+-.08KT	840000.00	110.00	107.00	62.30	1126520.00	32	24.00	
7	-3	TEAPOT ESS	NTS-A10	MAR55	ALLUV	NUC	1.2+-.1KT	2400000.00	67.00	146.00	90.00	2529200.00	30	19.00	
8	43	JANGLE U	NTS-A10	NOV51	ALLUV	NUC	1.2+-.1KT	2400000.00	17.00	129.00	53.00	972730 00	20	8.00	
500	43	JANGLE S	NTS-A10	OCT51	ALLUV	NUC	1.2+-.1KT	2400000.00	-3.50	45.00	17.00	49275.00 B	0	5.00	
501	21	JOHNIE BOY	NTS-A18	JUL62	ALLUV	NUC	.5+-.2KT	1000000.00	1.75	61.00	30.00	145000.00 B	0	10.00	
9	53	SCOOTER	NTS-A10	OCT60	ALLUV	TNT	987410 LB	987410.00	125.00	153.80	74.50	2642000.00	35	9.10	
10	86	STAGECOACH-1	NTS-A10	MAR60	ALLUV	TNT	40120 LB	40120.00	80.00	57.00	7.90	49145.00	22	4.80	
11	86	STAGECOACH-2	NTS-A10	MAR60	ALLUV	TNT	40240 LB	40240.00	17.10	50.50	23.60	83650.00	30	5.50	
12	86	STAGECOACH-3	NTS-A10	MAR60	ALLUV	TNT	40070 LB	40070.00	34.20	58.60	29.20	144600.00	30	6.20	
13	40	SANDIA SR I-2	NTS-A10	JAN59	ALLUV	TNT	256 LB	256.00	9.53	15.12	7.86	2146.00 B	0 B	0.00	
14	40	SANDIA SR I-4	NTS-A10	JAN59	ALLUV	TNT	256 LB	256.00	15.90	11.32	1.77	368.00 B	0 B	0.00	
15	40	SANDIA SR I-8	NTS-A10	JAN59	ALLUV	TNT	256 LB	256.00	6.35	13.13	7.30	1489.00 B	0 B	0.00	
16	40	SANDIA SR I-9	NTS-A10	JAN59	ALLUV	TNT	256 LB	256.00	9.53	14.14	7.16	1930.00 B	0 B	0.00	
17	40	SANDIA SR I-10	NTS-A10	JAN59	ALLUV	TNT	256 LB	256.00	12.70	13.40	4.10	1093.00 B	0 B	0.00	
18	40	SANDIA SR I-11	NTS-A10	JAN59	ALLUV	TNT	256 LB	256.00	15.90	6.53	.38	236.00 B	0 B	0.00	
19	40	SANDIA SR I-12	NTS-A10	JAN59	ALLUV	TNT	256 LB	256.00	19.05	9.36	2.30	256.00 B	0 B	0.00	
20	40	SANDIA SR I-15	NTS-A10	DEC58	ALLUV	TNT	256 LB	256.00	25.40	4.18	.45	31.00 B	0 B	0.00	
21	40	SANDIA SR I-16	NTS-A10	DEC58	ALLUV	TNT	256 LB	256.00	12.70	14.19	6.70	2220.00 B	0 B	0.00	
22	40	SANDIA SR I-17	NTS-A10	DEC58	ALLUV	TNT	256 LB	256.00	19.05	5.68	1.70	55.00 B	0 B	0.00	
23	40	SANDIA SR II-1	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	29.80	31.00	-.63	-584.00 B	0 B	0.00	
24	40	SANDIA SR II-2	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	28.50	37.70	-.83	-1079.00 B	0 B	0.00	

TABLE 2. CATALOGED CRATER DATA (CONTINUED)

IDENTIFICATION						EXPLOSIVE DATA			DEPTH OF BURST	APPARENT CRATER DIMENSIONS					RMK
EVT NO.	REF NO.	SERIES/SHOT NAME	SITE	DATE MO YR	MEDIUM	TYPE	YIELD	EQUIV WT LBS-TNT	FT	RADIUS FT	DEPTH FT	VOLUME CU FT	SLP DEG	LIP HT FT	SEE NTE
25	40	SANDIA SR II-3	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	26.10	32.30	-1.03	-1187.00 B	0 B	0.00	
26	40	SANDIA SR II-4	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	25.50	2.35	1.15	16.00 B	0 B	0.00	
27	40	SANDIA SR II-5	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	23.30	3.03	.30	16.00 B	0 B	0.00	
28	40	SANDIA SR II-6	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	22.60	4.39	1.00	170.00 B	0 B	0.00	
29	40	SANDIA SR II-7	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	19.70	8.13	1.01	121.00 B	0 B	0.00	
30	40	SANDIA SR II-8	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	19.00	10.07	1.60	297.00 B	0 B	0.00	
31	40	SANDIA SR II-9	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	16.40	14.29	2.61	716.00 B	0 B	0.00	
32	40	SANDIA SR II-10	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	16.10	14.10	4.55	1077.00 B	0 B	0.00	
33	40	SANDIA SR II-11	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	13.10	14.69	5.43	1670.00 B	0 B	0.00	
34	40	SANDIA SR II-12	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	0.00	8.57	2.49	161.00 B	0 B	0.00	
35	40	SANDIA SR II-13	NTS-A10	AUG59	ALLUV	TNT	256 LB	256.00	0.00	8.34	2.60	267.00 B	0 B	0.00	
36	59	MOLE-202	NTS-A10	SEP52	ALLUV	TNT	256 LB	256.00	6.35	11.30	5.50	1044.80	40	1.05	
37	59	MOLE-203	NTS-A10	SEP52	ALLUV	TNT	256 LB	256.00	3.18	8.35	3.95	355.60	43	.95	
38	59	MOLE-204	NTS-A10	OCT52	ALLUV	TNT	256 LB	256.00	1.65	9.45	2.60	363.60	40	.40	
39	59	MOLE-205	NTS-A10	OCT52	ALLUV	TNT	256 LB	256.00	.83	9.05	2.05	299.80	38	.80	
40	59	MOLE-206	NTS-A10	OCT52	ALLUV	TNT	256 LB	256.00	0.00	6.35	1.70	129.30	37	.80	
41	59	MOLE-207	NTS-A10	OCT52	ALLUV	TNT	256 LB	256.00	-.83	4.05	1.40	37.40	36	.50	
42	59	MOLE-212	NTS-A10	OCT52	ALLUV	TNT	256 LB	256.00	6.35	11.76	5.85	1206.90	43	1.60	
43	59	MOLE-401	NTS-A10	OCT54	ALLUV	TNT	256 LB	256.00	3.18	10.60	5.50	824.40	26	.60	
44	59	MOLE-402	NTS-A10	OCT54	ALLUV	TNT	256 LB	256.00	4.77	11.05	6.20	942.70	35	1.45	
45	59	MOLE-403	NTS-A10	OCT54	ALLUV	TNT	256 LB	256.00	.83	8.30	3.40	293.30	33	1.00	
46	59	MOLE-404	NTS-A10	OCT54	ALLUV	TNT	256 LB	256.00	6.35	11.75	6.00	1190.50	42	1.95	
47	59	MOLE-405	NTS-A10	NOV54	ALLUV	TNT	256 LB	256.00	1.65	9.20	4.55	498.20	35	.80	
48	59	MOLE-406	NTS-A10	NOV54	ALLUV	TNT	256 LB	256.00	3.18	9.85	4.00	672.70	45	1.25	
49	57	PRE-BUGGY-TEST	NTS-A5	DEC62	ALLUV	NM	1017 LB	1119.00	15.00	22.70	10.90	7200.00 B	0 B	0.00	19
50	57	PRE-BUGGY-1	NTS-A5	DEC62	ALLUV	NM	1003 LB	1103.00	15.00	21.00	9.70	6560.00 B	0	3.00	

TABLE 2. CATALOGED CRATER DATA (CONTINUED)

IDENTIFICATION						EXPLOSIVE DATA			DEPTH OF	APPARENT CRATER DIMENSIONS					RMK
EVT NO.	REF NO.	SERIES/SHOT NAME	SITE	DATE MO YR	MEDIUM	TYPE	YIELD	EQUIV WT LBS-TNT	BURST FT	RADIUS FT	DEPTH FT	VOLUME CU FT	SLP DEG	LIP HT FT	SEE NTE
51	57	PRE-BUGGY-2	NTS-A5	DEC62	ALLUV	NM	1011 LB	1112.00	16.60	21.80	9.10	7560.00 B	0 B	0.00	
52	57	PRE-BUGGY-3	NTS-A5	DEC62	ALLUV	NM	1011 LB	1112.00	18.20	20.90	7.80	5830.00 B	0	3.80	
53	57	PRE-BUGGY-4	NTS-A5	DEC62	ALLUV	NM	1009 LB	1110.00	19.80	20.60	9.40	6530.00 B	0	2.80	
54	57	PRE-BUGGY-5	NTS-A5	DEC62	ALLUV	NM	1016 LB	1118.00	21.40	19.70	4.10	2650.00 B	0 B	0.00	
55	57	PRE-BUGGY-6	NTS-A5	DEC62	ALLUV	NM	1015 LB	1117.00	19.60	20.70	8.30	6080.00 B	0 B	0.00	
56	66	PRE-BUGGY II-F1	NTS-A5	AUG63	ALLUV	NM	1000 LB	1100.00	19.80	22.70	11.80	7860.00 B	0	2.78	
57	66	PRE-BUGGY II-F2	NTS-A5	AUG63	ALLUV	NM	1000 LB	1100.00	19.80	21.20	11.80	6030.00 B	0	2.56	
58	66	PRE-BUGGY II-F3	NTS-A5	AUG63	ALLUV	TNT	950 LB	950.00	18.50	21.10	11.00	6950.00 B	0 B	0.00	
59	66	PRE-BUGGY II-F4	NTS-A5	AUG63	ALLUV	TNT	950 LB	950.00	18.33	22.10	10.80	7560.00 B	0 B	0.00	
60	85	BUCKBOARD-2	NTS-A18	JUN60	BASALT	TNT	1000 LB	1000.00	18.90	4.63	1.40	45.00 B	0 B	0.00	
61	85	BUCKBOARD-3	NTS-A18	JUN60	BASALT	TNT	1000 LB	1000.00	14.70	15.65	5.20	1800.00 B	0 B	0.00	
62	85	BUCKBOARD-4	NTS-A18	AUG60	BASALT	TNT	1000 LB	1000.00	9.60	16.70	6.50	2620.00 B	0 B	0.00	
63	85	BUCKBOARD-5	NTS-A18	JUL60	BASALT	TNT	1000 LB	1000.00	4.80	15.00	7.50	1890.00 B	0 B	0.00	
64	85	BUCKBOARD-7	NTS-A18	JUN60	BASALT	TNT	1000 LB	1000.00	18.60	10.67	3.80	654.00 B	0 B	0.00	
65	85	BUCKBOARD-8	NTS-A18	JUN60	BASALT	TNT	1000 LB	1000.00	14.70	16.92	8.80	3500.00 B	0 B	0.00	
66	85	BUCKBOARD-9	NTS-A18	AUG60	BASALT	TNT	1000 LB	1000.00	9.60	12.15	4.80	800.00 B	0 B	0.00	
67	85	BUCKBOARD-10	NTS-A18	JUL60	BASALT	TNT	1000 LB	1000.00	4.80	15.80	7.00	2660.00 B	[illegible] B	0.00	
68	85	BUCKBOARD-11	NTS-A18	SEP60	BASALT	TNT	39995 LB	39995.00	25.50	44.66	24.90	54220.00	29	5.00	
69	85	BUCKBOARD-12	NTS-A18	SEP60	BASALT	TNT	40000 LB	40000.00	42.70	57.00	34.70	135000.00	32	6.80	
70	85	BUCKBOARD-13	NTS-A18	AUG60	BASALT	TNT	39870 LB	39870.00	58.80	36.90	16.20	23200.00	24	9.40	
71	65	PRE-SCHOONER-A	NTS-A18	FEB64	BASALT	NM	39250 LB	43200.00	58.00	50.30	22.90	75800.00	30	12.30	
72	65	PRE-SCHOONER-B	NTS-A18	FEB64	BASALT	NM	39450 LB	43400.00	50.20	49.00	25.50	73900.00	31	10.20	
73	65	PRE-SCHOONER-C	NTS-A18	FEB64	BASALT	NM	39840 LB	43800.00	66.10	68.00	-1.30	-53300.00	34	15.90	
74	65	PRE-SCHOONER-D	NTS-A18	FEB64	BASALT	NM	39590 LB	43500.00	41.80	46.10	25.60	64800.00	32	8.70	
75	3	PRE-SCHOONER II	IDAHO	SEP65	RHYOLTE	NM	85.5 TONS	185000.00	71.70	95.20	60.70	669100.00	37	17.20	
76	23	PRE-GOLA I-CHAR	FPR MNT	OCT66	SHALE	NM	19.62 TNS	43160.00	42.49	80.40	32.60	277550.00	29	14.50	

TABLE 2. CATALOGED CRATER DATA (CONTINUED)

IDENTIFICATION						EXPLOSIVE DATA			DEPTH OF	APPARENT CRATER DIMENSIONS					RMK
EVT NO.	REF NO.	SERIES/SHOT NAME	SITE	DATE MO YR	MEDIUM	TYPE	YIELD	EQUIV WT LBS-TNT	BURST FT	RADIUS FT	DEPTH FT	VOLUME CU FT	SLP DEG	LIP HT FT	SEE NTE
77	23	PRE-GOLA I-BRAV	FPR MNT	OCT66	SHALE	NM	19.36 TNS	42590.00	46.25	78.50	29.50	241260.00	29	13.70	
78	23	PRE-GOLA I-ALPH	FPR MNT	NOV66	SHALE	NM	20.35 TNS	44770.00	52.71	76.10	32.10	235300.00	29	13.90	
79	23	PRE-GOLA I-DELT	FPR MNT	NOV66	SHALE	NM	20.24 TNS	44530.00	56.87	65.10	25.20	133880.00	29	13.00	
80	23	PRE-GOLA I-SC-4	FPR MNT	JUN66	SHALE	NM	1000 LB	1100.00	12.20	24.50	13.00	8100.00	28	3.80	
81	23	PRE-GOLA I-SC-2	FPR MNT	JUN66	SHALE	NM	1000 LB	1100.00	15.30	27.30	12.50	9700.00	26	3.10	
82	23	PRE-GOLA I-SC-1	FPR MNT	JUN66	SHALE	NM	1000 LB	1100.00	19.10	7.10	2.80	150.00	18	3.70	
83	23	PRE-GOLA I-SC-3	FPR MNT	JUN66	SHALE	NM	1000 LB	1100.00	23.30	14.60	3.40	750.00	15	4.30	
84	7	TOBOGGAN-E1A	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	0.00	1.55	.91	2.33 B	0 B	0.00	
85	7	TOBOGGAN-E1B	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	0.00	1.47	.67	1.76 B	0 B	0.00	
86	7	TOBOGGAN-E1C	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	0.00	1.31	.65	1.54 B	0 B	0.00	
87	7	TOBOGGAN-E2A	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	.50	2.55	1.11	11.55 B	0 B	0.00	
88	7	TOBOGGAN-E2B	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	.50	2.25	1.06	8.00 B	0 B	0.00	
89	7	TOBOGGAN-E2C	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	.50	2.43	1.44	11.56 B	0 B	0.00	
90	7	TOBOGGAN-E3A	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	1.00	2.78	1.60	15.69 B	0 B	0.00	
91	7	TOBOGGAN-E3.5A	NTS-A6	JUN60	PLAYA	TNT	8 LB	8.00	1.50	2.85	1.71	18.10 B	0 B	0.00	
92	7	TOBOGGAN-E3B	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	1.00	3.02	1.54	17.03 B	0 B	0.00	
93	7	TOBOGGAN-E3C	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	1.00	2.70	1.75	15.68 B	0 B	0.00	
94	7	TOBOGGAN-E4A	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	2.00	3.43	1.77	26.64 B	0 B	0.00	
95	7	TOBOGGAN-E4.5A	NTS-A6	JUN60	PLAYA	TNT	8 LB	8.00	2.50	3.75	1.48	27.40 B	0 B	0.00	
96	7	TOBOGGAN-E4B	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	2.00	3.56	1.94	34.32 B	0 B	0.00	
97	7	TOBOGGAN-E4.5B	NTS-A6	JUN60	PLAYA	TNT	8 LB	8.00	2.50	3.31	1.01	13.00 B	0 B	0.00	
98	7	TOBOGGAN-E4C	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	2.00	3.67	1.81	36.37 B	0 B	0.00	
99	7	TOBOGGAN-E5A	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	3.00	3.68	.80	16.82 B	0 B	0.00	
100	7	TOBOGGAN-E5.5A	NTS-A6	JUN60	PLAYA	TNT	8 LB	8.00	3.50	3.16	.34	7.05 B	0 B	0.00	
101	7	TOBOGGAN-E5B	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	3.00	4.00	1.79	38.70 B	0 B	0.00	
102	7	TOBOGGAN-E5C	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	3.00	3.66	.67	13.72 B	0 B	0.00	

TABLE 2. CATALOGED CRATER DATA (CONTINUED)

IDENTIFICATION						EXPLOSIVE DATA			DEPTH OF	APPARENT CRATER DIMENSIONS					RMK
EVT NO.	REF NO.	SERIES/SHOT NAME	SITE	DATE MO YR	MEDIUM	TYPE	YIELD	EQUIV WT LBS-TNT	BURST FT	RADIUS FT	DEPTH FT	VOLUME CU FT	SLP DEG	LIP HT FT	SEE NTE
103	7	TOBOGGAN-E6A	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	4.00	1.90	.20	1.24 B	0 B	0.00	
104	7	TOBOGGAN-E6.5A	NTS-A6	JUN60	PLAYA	TNT	8 LB	8.00	4.50	0.00	0.00	0.00 B	0 B	0.00	
105	7	TOBOGGAN-E6B	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	4.00	1.50	.12	.52 B	0 B	0.00	
106	7	TOBOGGAN-E6C	NTS-A6	NOV59	PLAYA	TNT	8 LB	8.00	4.00	2.40	.11	2.22 B	0 B	0.00	
107	7	TOBOGGAN-E7A	NTS-A6	JUN60	PLAYA	TNT	8 LB	8.00	5.00	0.00	0.00	0.00 B	0 B	0.00	
108	9	MTCE-S1(C1)	YFC WSH	JUN65	BASALT	TNT	4000 LB	4000.00	0.00	12.10	3.60	733.00	15	1.20	
109	9	MTCE-S2A	YFC WSH	JUN65	BASALT	TNT	4000 LB	4000.00	0.00	10.70	4.00	672.00	23	1.40	
110	9	MTCE-S3A	YFC WSH	JUN65	BASALT	TNT	4000 LB	4000.00	0.00	11.40	4.00	853.00	26	1.70	
111	9	MTCE-S4A	YFC WSH	JUN65	BASALT	TNT	4000 LB	4000.00	0.00	10.30	4.00	605.00	28	1.[illegible]	
112	9	MTCE-C2	YFC WSH	JUN65	BASALT	TNT	4000 LB	4000.00	2.20	14.00	5.30	1500.00	29	1.30	
113	9	MTCE-LS	YFC WSH	JUL65	BASALT	TNT	16000 LB	16000.00	0.00	18.70	5.40	3659.24	24	1.80	
132	5	ZULU II-M9	LRL 300	NOV65	SAND	C-4	1 LB	1.30	0.00	1.48	.52	1.61	26	.13	19
133	5	ZULU II-M11	LRL 300	NOV65	SAND	C-4	1 LB	1.30	0.00	1.34	.53	1.35 $	26	.16	19
134	5	ZULU II-M12	LRL 300	NOV65	SAND	C-4	1 LB	1.30	0.00	1.44	.50	1.46 $	26	.20	19
135	5	ZULU II-M6	LRL 300	OCT65	SAND	C-4	1 LB	1.30	.50	2.34	1.09	8.46 $	34	.24	19
136	5	ZULU II-M7	LRL 300	NOV65	SAND	C-4	1 LB	1.30	.50	2.07	.98	5.95 $	34	.25	19
137	5	ZULU II-M10	LRL 300	NOV65	SAND	C-4	1 LB	1.30	.50	2.28	1.00	7.35	34	.25	19
138	5	ZULU II-M2	LRL 300	OCT65	SAND	C-4	1 LB	1.30	1.00	2.55	1.51	13.90	36	.22	19
139	5	ZULU II-M4	LRL 300	OCT65	SAND	C-4	1 LB	1.30	1.00	2.64	1.55	15.25 $	36	.31	19
140	5	ZULU II-M5	LRL 300	OCT65	SAND	C-4	1 LB	1.30	1.00	2.54	1.60	14.60 $	36	.28	19
141	5	ZULU II-SS18	LRL 300	MAR66	SAND	C-4	1 LB	1.30	1.40	2.61	1.89	18.20	39	.29	19
142	5	ZULU II-SS19	LRL 300	APR66	SAND	C-4	1 LB	1.30	1.40	2.53	1.92	17.40 $	39	.32	19
143	5	ZULU II-M1	LRL 300	OCT65	SAND	C-4	1 LB	1.30	1.50	2.63	1.74	17.00 $	38	.26	19
144	5	ZULU II-M3	LRL 300	OCT65	SAND	C-4	1 LB	1.30	1.50	2.46	1.73	14.80 $	38	.36	19
145	5	ZULU II-M8	LRL 300	NOV65	SAND	C-4	1 LB	1.30	1.50	2.54	1.76	16.00	38	.40	19
146	5	ZULU II-SS17	LRL 300	MAR66	SAND	C-4	1 LB	1.30	1.60	2.57	1.97	18.40 $	39	.38	19

TABLE 2. CATALOGED CRATER DATA (CONTINUED)

IDENTIFICATION						EXPLOSIVE DATA			DEPTH OF BURST FT	APPARENT CRATER DIMENSIONS					RMK
EVT NO.	REF NO.	SERIES/SHOT NAME	SITE	DATE MO YR	MEDIUM	TYPE	YIELD	EQUIV WT LBS-TNT		RADIUS FT	DEPTH FT	VOLUME CU FT	SLP DEG	LIP HT FT	SEE NTE
147	5	ZULU II-SS20	LRL 300	APR66	SAND	C-4	1 LB	1.30	1.60	2.55	1.91	17.55	39	.36	19
148	5	ZULU II-15	LRL 300	SEP65	SAND	C-4	1 LB	1.30	1.75	2.50	1.55	13.78	38	.39	19
149	5	ZULU II-8	LRL 300	SEP65	SAND	C-4	1 LB	1.30	1.75	2.47	1.49	12.85	$ 38	.30	19
150	5	ZULU II-SS21	LRL 300	MAY66	SAND	C-4	1 LB	1.30	1.80	2.41	1.51	12.40	$ 38	.39	19
151	5	ZULU II-10	LRL 300	AUG65	SAND	C-4	1 LB	1.30	1.98	2.27	1.26	9.18	$ 37	.46	19
152	5	ZULU II-SS7	LRL 300	NOV65	SAND	C-4	1 LB	1.30	1.99	1.99	.70	3.92	$ 37	.36	19
153	5	ZULU II-1	LRL 300	AUG65	SAND	C-4	1 LB	1.30	2.00	2.25	1.35	9.67	$ 35	.49	19
154	5	ZULU II-16	LRL 300	SEP65	SAND	C-4	1 LB	1.30	2.00	2.41	1.17	9.60	36	.34	19
155	5	ZULU II-19	LRL 300	OCT65	SAND	C-4	1 LB	1.30	2.00	2.24	1.08	7.67	33	.50	19
156	5	ZULU II-SS5	LRL 300	NOV65	SAND	C-4	1 LB	1.30	2.00	2.18	1.01	6.78	32	.52	19
157	5	ZULU II-SS10	LRL 300	DEC65	SAND	C-4	1 LB	1.30	2.00	2.38	1.21	9.68	36	.33	19
158	5	ZULU II-SS14	LRL 300	FEB66	SAND	C-4	1 LB	1.30	2.00	2.26	.85	6.13	$ 32	.49	19
159	5	ZULU II-SS16	LRL 300	FEB66	SAND	C-4	1 LB	1.30	2.00	2.44	1.02	8.58	$ 35	.39	19
160	5	ZULU II-SS22	LRL 300	MAY66	SAND	C-4	1 LB	1.30	2.01	2.07	.78	4.72	$ 32	.41	19
161	5	ZULU II-SS8	LRL 300	NOV65	SAND	C-4	1 LB	1.30	2.11	2.19	.78	5.29	33	.49	19
162	5	ZULU II-SS9	LRL 300	DEC65	SAND	C-4	1 LB	1.30	2.11	1.83	.60	2.84	$ 28	.43	19
163	5	ZULU II-SS24	LRL 300	SEP66	SAND	C-4	1 LB	1.30	2.11	2.05	.40	2.38	$ 28	.41	19
164	28	ZULU-1A	NTS-A5	JUL64	ALLUV	C-4	1 LB	1.30	2.00	2.48	1.28	11.10	31	.21	19
165	28	ZULU-1B	NTS-A5	JUL64	ALLUV	C-4	1 LB	1.30	2.00	2.40	1.15	9.36	30	.29	19
166	28	ZULU-1C	NTS-A5	JUL64	ALLUV	C-4	1 LB	1.30	2.00	2.34	1.39	10.75	31	.26	19
167	28	ZULU-2A	NTS-A5	JUL64	ALLUV	C-4	1 LB	1.30	2.00	2.65	1.43	14.20	34	.30	19
168	28	ZULU-2B	NTS-A5	JUL64	ALLUV	C-4	1 LB	1.30	2.00	2.52	1.40	12.60	32	.35	19
169	28	ZULU-3A	NTS-A5	JUL64	ALLUV	C-4	1 LB	1.30	2.00	2.42	1.41	11.70	35	.31	19
170	28	ZULU-3B	NTS-A5	JUL64	ALLUV	C-4	1 LB	1.30	2.00	2.55	1.39	12.80	35	.29	19
171	28	ZULU-3C	NTS-A5	JUL64	ALLUV	C-4	1 LB	1.30	2.00	2.63	1.52	14.85	33	.37	19
172	28	ZULU-4C	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	2.00	2.54	1.44	13.15	34	.34	19

TABLE 2. CATALOGED CRATER DATA (CONTINUED)

IDENTIFICATION						EXPLOSIVE DATA			DEPTH OF	APPARENT CRATER DIMENSIONS					RMK
EVT NO.	REF NO.	SERIES/SHOT NAME	SITE	DATE MO YR	MEDIUM	TYPE	YIELD	EQUIV WT LBS-TNT	BURST FT	RADIUS FT	DEPTH FT	VOLUME CU FT	SLP DEG	LIP HT FT	SEE NTE
173	28	ZULU-4B	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	.50	2.14	1.10	7.12	33 B	0.00	19
174	28	ZULU-5A	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	.50	2.16	1.10	7.26	28	.21	19
175	28	ZULU-5B	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	1.50	2.45	1.24	10.50	32	.37	19
176	28	ZULU-6A	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	1.00	2.20	1.23	8.41	32	.26	19
177	28	ZULU-6B	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	2.00	2.17	.85	5.66	25	.32	19
178	28	ZULU-7A	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	1.00	2.25	1.30	9.30	34	.25	19
179	28	ZULU-8C	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	.50	1.91	1.09	5.62	28	.18	19
180	66	ZULU-9A	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	2.00	2.16	.87	5.74	24	.29	19
181	28	ZULU-9C	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	1.50	2.28	1.14	8.37	28	.37	19
182	28	ZULU-10A	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	2.00	2.41	1.11	9.10	29	.26	19
183	28	ZULU-10B	NTS-A5	AUG64	ALLUV	C-4	1 LB	1.30	2.50	2.45	-.98	-8.17	-26	.23	19
184	28	ZULU-11A	NTS-A5	SEP64	ALLUV	C-4	1 LB	1.30	1.75	2.38	1.12	8.96	29	.32	19
185	41	SANDIA-TUFF 1	NTS-A14	APR59	TUFF	TNT	256 LB	256.00	7.37	15.00	4.90	1266.00 B	0 B	0.00	
186	41	SANDIA-TUFF 2	NTS-A14	APR59	TUFF	TNT	256 LB	256.00	9.62	13.90	4.20	1100.00 B	0 B	0.00	
187	41	SANDIA-TUFF 6	NTS-A14	APR59	TUFF	TNT	256 LB	256.00	6.92	11.70	4.30	591.00 B	0 B	0.00	
188	41	SANDIA-TUFF 7	NTS-A14	APR59	TUFF	TNT	256 LB	256.00	10.37	6.90	2.30	112.00 B	0 B	0.00	
189	41	SANDIA-TUFF 11	NTS-A14	APR59	TUFF	TNT	256 LB	256.00	9.32	11.60	1.80	357.00 B	0 B	0.00	
200	18	AIR VENT I-1	NTS-A5	DEC63	PLAYA	TNT	40000 LB	40000.00	17.19	47.61	22.50	72500.00	36 B	0.00	
201	18	AIR VENT II-1	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	-.87	3.20	.82	13.13 B	0 B	0.00	
202	18	AIR VENT II-2A	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	0.00	5.54	2.39	95.46 B	0 B	0.00	
203	18	AIR VENT II-2B	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	0.00	5.40	2.43	93.22 B	0 B	0.00	
204	18	AIR VENT II-3	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	.87	6.72	3.38	235.40 B	0 B	0.00	
205	18	AIR VENT II-4	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	1.59	7.62	3.72	247.00 B	0 B	0.00	
206	18	AIR VENT II-5A	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	3.18	8.84	4.13	426.00 B	0 B	0.00	
207	18	AIR VENT II-5B	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	3.18	8.50	4.35	381.00 B	0 B	0.00	
208	18	AIR VENT II-6	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	4.76	9.58	4.64	517.00 B	0 B	0.00	

TABLE 2. CATALOGED CRATER DATA (CONTINUED)

IDENTIFICATION						EXPLOSIVE DATA			DEPTH	APPARENT CRATER DIMENSIONS					RMK
EVT NO.	REF NO.	SERIES/SHOT NAME	SITE	DATE MO YR	MEDIUM	TYPE	YIELD	EQUIV WT LBS-TNT	OF BURST FT	RADIUS FT	DEPTH FT	VOLUME CU FT	SLP DEG	LIP HT FT	SEE NTE
209	18	AIR VENT II-7A	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	6.35	9.82	4.36	505.70 B	0 B	0.00	
210	18	AIR VENT II-7B	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	6.35	9.94	4.49	544.00 B	0 B	0.00	
211	18	AIR VENT II-8	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	7.94	10.32	3.98	483.00 B	0 B	0.00	
212	18	AIR VENT II-9A	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	9.53	10.98	3.63	486.00 B	0 B	0.00	
213	18	AIR VENT II-9B	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	9.53	11.02	2.34	332.00 B	0 B	0.00	
214	18	AIR VENT II-10A	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	12.70	22.90	-3.81	-1178.00 B	0 B	0.00	
215	18	AIR VENT II-10B	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	12.70	26.40	-4.13	-2500.00 B	0 B	0.00	
216	18	AIR VENT II-11A	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	15.90	22.60	-4.11	-2678.00 B	0 B	0.00	
217	18	AIR VENT II-11B	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	15.90	22.30	-4.41	-2722.00 B	0 B	0.00	
218	18	AIR VENT II-12	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	19.05	22.00	-2.67	-1878.00 B	0 B	0.00	
219	18	AIR VENT II-13	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	22.20	23.40	-1.35	-1003.00 B	0 B	0.00	
220	18	AIR VENT II-14	NTS-A5	JAN64	PLAYA	TNT	256 LB	256.00	25.40	24.70	-.63	-900.00 B	0 B	0.00	
221	18	AIR VENT III-1A	NTS-A5	JAN64	PLAYA	TNT	64 LB	64.00	0.00	3.41	1.57	24.02 B	0 B	0.00	
222	18	AIR VENT III-1B	NTS-A5	JAN64	PLAYA	TNT	64 LB	64.00	0.00	3.41	1.82	26.10 B	0 B	0.00	
223	18	AIR VENT III-1C	NTS-A5	JAN64	PLAYA	TNT	64 LB	64.00	0.00	3.26	1.81	22.79 B	0 B	0.00	
224	18	AIR VENT III-1D	NTS-A5	JAN64	PLAYA	TNT	64 LB	64.00	0.00	3.52	1.87	28.33 B	0 B	0.00	
225	18	AIR VENT III-2A	NTS-A5	JAN64	PLAYA	TNT	1000 LB	1000.00	0.00	9.36	4.27	442.00 B	0 B	0.00	
226	18	AIR VENT III-2B	NTS-A5	JAN64	PLAYA	TNT	1000 LB	1000.00	0.00	10.12	4.55	517.00 B	0 B	0.00	
227	18	AIR VENT III-2C	NTS-A5	JAN64	PLAYA	TNT	1000 LB	1000.00	0.00	8.92	4.27	440.00 B	0 B	0.00	
228	18	AIR VENT III-3A	NTS-A5	JAN64	PLAYA	TNT	6000 LB	6000.00	0.00	16.44	6.57	2520.00 B	0 B	0.00	
229	18	AIR VENT III-3B	NTS-A5	JAN64	PLAYA	TNT	6000 LB	6000.00	0.00	17.52	6.91	2703.00 B	0 B	0.00	
502	58	FLAT TOP I	NTS-A9	JUN64	LIMESTN	TNT	20 TONS	40000.00	0.00	27.00	9.50	9990.00 B	0	3.60	
503	58	FLAT TOP II	NTS-A5	FEB64	PLAYA	TNT	20 TONS	40000.00	0.00	36.00	11.30	24030.00 B	0	3.90	
504	58	FLAT TOP III	NTS-A5	MAR64	PLAYA	TNT	20 TONS	40000.00	0.00	39.00	18.00	37800.00 B	0	5.30	

TABLE 3. CATALOGED MATERIAL PROPERTY DATA

SHOT IDENT.		MATERIAL				WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS							
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
1	SCHOONER	5562	TUFF	ROCK	72	2.56	108.6	7.0 $	1400 B	0 $	15000 $	.0050 $	25000 $	200 $	.0090
2	CABRIOLET	6197	RHYOLITE	ROCK	29	2.63	153.1 $	1.5	862	380	12220	.0032	45980	5000	.0117
3	PALANQUIN	6190	RHYOLITE	ROCK	49	2.62	155.0 $	1.5 $	930 B	0	13370	.0035 $	50000	5000 $	.0120
4	SULKY	5328	BASALT	ROCK	52	2.64	164.5 $	1.5 $	2600 B	0	14470	.0038 $	28000	200 $	.0045
5	SEDAN	4320	ALLUV	SP-SM	69	2.60	110.0	12.5	7 B	0 $	11 $	.0200	293	69	.0850
6	DANNY BOY	5475	BASALT	ROCK	50	2.84	160.0 $	1.5	1955 B	0	24215	.0038	40420	2000 $	.0055
7	TEAPOT ESS	4226	ALLUV	SP-SM	43 $	2.58 $	95.0 $	6.5 $	3 B	0 $	5 $	.0200 $	300 $	80 $	.0950
8	JANGLE U	4299	ALLUV	SP-SM	43	2.55	91.0 $	7.0 $	3 B	0 $	5 $	.0200 $	300 $	80 $	.0950
500	JANGLE S	4212	ALLUV	SP-SM	43	2.58	87.0 $	8.0 $	3 B	0 $	5 $	.0200 $	360 $	80 $	.0950
501	JOHNIE BOY $	5000	ALLUV	SP-SM	21 $	2.58	112.0	2.9 B	0 B	0 B	0	80.0000 B	0 B	0	80.0000
9	SCOOTER	4322	ALLUV	SP-SM	53 $	2.60	87.0	7.5 $	3 B	0 $	5 $	.0200 $	300 $	100 $	.1000

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
1 $	42.0 $	2000 $	.13 $	1.05 B	0 $	1360000 $	580000	5685 $	4000 B	0.0 B	0.0 $	70 $	27100 $	82700	1
2	45.0	1660	.21	1.10	3110000	2230000	1130000	6900 $	4900 B	0.0 B	0.0	74 $	28000 $	71000	1,2
3 $	48.0 $	1660	.26 $	1.20	3800000 $	2700000 $	1400000	6237 $	4400 B	0.0 B	0.0	53 $	28000 $	71000	1,3
4 $	36.0 $	3100 $	.15 $	1.40	5620000	6370000 $	2900000 $	14000 $	9000 B	0.0 B	0.0	96 $	28524 $	59426	1,4
5	38.0	21 $	.40 $	1.22 B	0 $	17000 $	6000	4200 $	2300 B	0.0 B	0.0 $	98 $	27100 $	82700	1,5
6	46.0	4400	.15	1.39	5250000	7140000	2880000	15280	9430 B	0.0 B	0.0 $	90 $	28524 $	59426	1,6
7 $	40.0 $	15 $	.40 $	1.18 B	0 $	15200 $	5500 $	3000 $	2300 B	0.0 B	0.0 $	98 $	27100 $	82700	1,7
8	48.0 $	18 $	.40 $	1.18 B	0 $	15200 $	5500 $	3000 $	2000 B	0.0 B	0.0 $	98 $	27100 $	82700	1,7
500	48.0 $	18 $	.40 $	1.18 B	0 $	15200 $	5500 $	3000 $	2000 B	0.0 B	0.0 $	98 $	27100 $	82700	1,7
501 $	45.0 $	12	80.00 B	0.00 B	0 B	0 B	0 $	3000 $	2000 B	0.0 B	0.0 B	0 $	27100 $	82700	
9 $	39.0 $	15 $	.40 $	1.13 B	0 $	14000 $	5000 $	2800 $	1800 B	0.0 B	0.0 $	98 B	0 B	0	7

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SF GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
10	STAGECOACH-1	4344	ALLUV	SP-SM	86	2.55	101.1	6.1 $	3 B	0 $	5 $	.0200 $	300 $	100 $	.1000
11	STAGECOACH-2	4323	ALLUV	SP-SM	86	2.55	99.7	8.0 $	3 B	0 $	5 $	.0200 $	300 $	100 $	.1000
12	STAGECOACH-3	4332	ALLUV	SP-SM	86	2.55	101.2	6.6 $	3 B	0 $	5 $	.0200 $	300 $	100 $	.1000
13	SANDIA SR I-2	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
14	SANDIA SR I-4	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
15	SANDIA SR I-5	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
16	SANDIA SR I-9	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
17	SANDIA SP I-10	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
18	SANDIA SR I-11	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
19	SANDIA SR I-12	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
20	SANDIA SR I-15	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
10 $	40.0 $	15 $	.40 $	1.20 B	0 $	17000 $	6000 $	3000 $	2000 B	0.0 B	0.0 $	98 B	0 B	0	8
11 $	48.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	98 B	0 B	0	8
12 $	42.0 $	15 $	.40 $	1.20 B	0 $	17000 $	5000 $	3000 $	2000 B	0.0 B	0.0 $	98 B	0 B	0	8
13 $	48.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
14 $	48.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
15 $	46.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
16 $	48.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
17 $	47.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
18 $	47.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
19 $	47.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
20 $	47.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

EVT NO.	SHOT IDENT. SERIES/SHOT NAME	ELEV FT	MATERIAL MEDIUM	USCS CLASS	REF NO.	WT-VOL RELATIONSHIPS SP GR	DRY UNT LB/CUFT	MOIST PR CT	STRENGTHS AND STRAINS TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
21	SANDIA SR I-16	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
22	SANDIA SR I-17	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
23	SANDIA SR II-1	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
24	SANDIA SR II-2	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
25	SANDIA SR II-3	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
26	SANDIA SR II-4	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
27	SANDIA SR II-5	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
28	SANDIA SR II-6	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
29	SANDIA SR II-7	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
30	SANDIA SR II-8	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
31	SANDIA SR II-9	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000

EVT NO.	ADDN STR-STN PARAMETERS PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	MODULUS VALUES SECANT PSI	YOUNGS PSI	SHEAR PSI	WAVE VELOCITIES SEISMIC FPS	SHEAR FPS	ATTBRG LIMITS LL PR CT	PI PR CT	CORE RECOV PR CT	INTERNAL ENERGIES MELT MPSI/CIN	VAPOR MPSI/CIN	REMKS SEE NOTE
21 $	47.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
22 $	47.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
23 $	47.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
24 $	47.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
25 $	47.0 $	15 $	.40 $	1.20 B	0 $	16000 $	5700 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
26 $	47.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
27 $	47.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
28 $	47.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
29 $	47.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
30 $	47.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
31 $	48.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS							
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-O PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
32	SANDIA SR II-10	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
33	SANDIA SR II-11	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
34	SANDIA SR II-12	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
35	SANDIA SR II-13	4300	ALLUV	SP-SM	86 $	2.55 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
36	MOLE-202 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
37	MOLE-203 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
38	MOLE-204 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
39	MOLE-205 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
40	MOLE-206 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
41	MOLE-207 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
42	MOLE-212 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
32 $	48.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
33 $	48.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
34 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
35 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
36 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
37 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
38 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
39 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
40 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
41 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
42 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
43	MOLE-401 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
44	MOLE-402 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
45	MOLE-403 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
46	MOLE-404 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
47	MOLE-405 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
48	MOLE-406 $	4300	ALLUV	SP-SM	86 $	2.56 $	100.0 $	8.0 $	2 B	0 $	4 $	.0200 $	300 $	100 $	.1000
49	PRE-BUGGY-TEST $	3180	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
50	PRE-BUGGY-1	3184	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
51	PRE-BUGGY-2	3192	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
52	PRE-BUGGY-3	3180	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
53	PRE-BUGGY-4	3177	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPUR MPSI/CIN	SEE NOTE
43 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
44 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
45 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
46 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
47 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
48 $	46.0 $	15 $	.40 $	1.20 B	0 $	160000 $	57000 $	3000 $	2000 B	0.0 B	0.0 $	95 B	0 B	0	9
49 $	46.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
50 $	43.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
51 $	43.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
52 $	43.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
53 $	43.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
54	PRE-BUGGY-5	3173	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
55	PRE-BUGGY-6	3170	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
56	PRE-BUGGY II-F1	3173	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
57	PRE-BUGGY II-F2	3173	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
58	PRE-BUGGY II-F3	3176	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
59	PRE-BUGGY II-F4	3174	ALLUV	SP-SM	57 $	2.55 $	95.0	5.5 $	1 B	0 $	3 $	.0200 $	280 $	100 $	.1000
60	BUCKBOARD-2	5301	BASALT	ROCK	85	2.81	159.2 $	1.5 $	1600 B	0	14030 $	.0048 $	15300 $	100 $	.0037
61	BUCKBOARD-3	5246	BASALT	ROCK	85	2.80	151.7 $	1.5 $	1650 B	0	15750 $	.0048 $	15300 $	100 $	.0037
62	BUCKBOARD-4	5235	BASALT	ROCK	85	2.80	161.1 $	1.5 $	2900 B	0	19960 $	.0052 $	23200 $	200 $	.0042
63	BUCKBOARD-5	5506	BASALT	ROCK	85	2.80	170.0 $	1.5 $	2100 B	0	31130 $	.0050 $	32000 $	100 $	.0050
64	BUCKBOARD-7	5251	BASALT	ROCK	85 $	2.73	138.0 $	1.5 $	1600 B	0	13250 $	.0023 $	15200 $	100 $	.0037

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS		CORE	INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BLK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
54 $	48.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
55 $	48.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
56 $	48.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
57 $	48.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
58 $	48.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
59 $	48.0 $	12 $	.40 $	1.15 B	0 $	170000 $	60000 $	3000 $	2000 B	0.0 B	0.0 $	90 B	0 B	0	10
60 $	45.0 $	3200 $	.18 $	1.39 $	5200000 $	7100000 $	2860000 $	15300 $	9450 B	0.0 B	0.0 $	99 B	0 B	0	11
61 $	45.0 $	3300 $	.18 $	1.39 $	5200000 $	7100000 $	2860000 $	15300 $	9450 B	0.0 B	0.0 $	99 B	0 B	0	11
62 $	45.0 $	4500 $	.15 $	1.39 $	6520000 $	7340000 $	2950000 $	15300 $	9400 B	0.0 B	0.0 $	100 B	0 B	0	11
63 $	45.0 $	4600 $	.21 $	1.39 $	6700000 $	9390000 $	3240000 $	15600 $	9500 B	0.0 B	0.0 $	100 B	0 B	0	11
64 $	28.0 $	1700 $	.18 $	1.20 $	4400000 $	6200000 $	2560000 $	14000 $	3700 B	0.0 B	0.0 $	100 B	0 B	0	11

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.		MATERIAL				WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
65	BUCKBOARD-8	5313	BASALT	ROCK	85	2.80	162.0 $	1.5 $	1700 B	0	15320 $	.0050 $	15300 $	100 $	.0037
66	BUCKBOARD-9	5228	BASALT	ROCK	85	2.80	162.0 $	1.5 $	2900 B	0	18880 $	.0051 $	22200 $	200 $	.0041
67	BUCKBOARD-10	5512	BASALT	ROCK	85	2.80	166.0 $	1.5 $	1900 B	0	23770 $	.0052 $	28000 $	200 $	.0040
68	BUCKBOARD-11	5237	BASALT	ROCK	85	2.80	160.0 $	1.5 $	2600 B	0	15290 $	.0041 $	15300 $	100 $	.0037
69	BUCKBOARD-12	5515	BASALT	ROCK	85	2.80	156.0 $	1.5 $	1900 B	0	21260 $	.0050 $	25000 $	200 $	.0040
70	BUCKBOARD-13	5242	BASALT	ROCK	85	2.80	164.0 $	1.5 $	1700 B	0	17140 $	.0050 $	17000 $	100 $	.0040
71	PRE-SCHOONER-A	5375	BASALT	ROCK	51 $	2.81	164.0 $	1.5	2930 B	0	13000	.0043	24670	2000 $	.0050
72	PRE-SCHOONER-B	5363	BASALT	ROCK	51 $	2.81	162.0 $	1.5	2900 B	0	17300	.0047 $	28000 $	2000 $	.0050
73	PRE-SCHOONER-C	5378	BASALT	ROCK	51 $	2.81	160.0 $	1.5	2370 B	0	8500	.0033	6820	1200 $	.0050
74	PRE-SCHOONER-D	5386	BASALT	ROCK	51 $	2.81	160.0 $	1.5	2370 B	0	12000	.0030 $	6000 $	200 $	.0050
75	PRE-SCHOONER II	4629	RHYOLITE	ROCK	33	2.50	149.0 $	1.5 $	800 $	350	10000	.0030 $	37000	5000	.0120

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
65 $	45.0 $	3300 $	.18 $	1.39 $	5200000 $	7100000 $	2860000 $	15300 $	9450 B	0.0 B	0.0 $	99 B	0 B	0	11
66 $	45.0 $	4500 $	.18 $	1.39 $	6520000 $	7340000 $	2950000 $	15300 $	9400 B	0.0 B	0.0 $	100 B	0 B	0	11
67 $	45.0 $	4500 $	.20 $	1.39 $	6380000 $	7000000 $	3240000 $	16000 $	10000 B	0.0 B	0.0 $	100 B	0 B	0	11
68 $	45.0 $	3300 $	.19 $	1.39 $	4460000 $	8410000 $	3190000 $	15300 $	9450 B	0.0 B	0.0 $	99 B	0 B	0	11
69 $	45.0 $	4500 $	.20 $	1.39 $	6380000 $	7000000 $	3240000 $	16000 $	10000 B	0.0 B	0.0 $	100 B	0 B	0	11
70 $	45.0 $	3300 $	.18 $	1.39 $	5200000 $	7100000 $	2860000 $	15300 $	9450 B	0.0 B	0.0 $	99 B	0 B	0	11
71	39.0	3520	.25	1.48	4000000	5000000	2500000 $	15000 $	9200 B	0.0 B	0.0 $	100 B	0 B	0	12
72 $	45.0 $	3500 $	.25	1.48 $	4000000 $	5000000 $	2500000 $	15030 $	9200 B	0.0 B	0.0 $	100 B	0 B	0	12
73	28.0	1720	.25	1.48	4400000	5500000 $	2500000 $	14100 $	8900 B	0.0 B	0.0 $	99 B	0 B	0	12
74 $	28.0 $	1720	.40	1.54	4720000	6670000 $	2560000 $	14100 $	8900 B	0.0 B	0.0 $	100 B	0 B	0	12
75 $	48.0 $	1600	.19	1.31	3330000 $	2300000 $	1200000	13000 $	9300 B	0.0 B	0.0	72 B	0 B	0	

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.		MATERIAL				WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS							
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
76	PRE-GOLA I-CHAR	2253	SHALE	CH	17	2.74	110.0	22.0 $	25 B	0	200 $	.0040 $	250 $	75 $	.0050
77	PRE-GOLA I-BRAV	2246	SHALE	CH	17	2.74	110.0	22.0 $	25 B	0	200 $	.0040 $	250 $	75 $	.0050
78	PRE-GOLA I-ALPH	2247	SHALE	CH	17	2.74	110.0	22.0 $	31 B	0	250 $	.0040 $	310 $	75 $	.0050
79	PRE-GOLA I-DELT	2272	SHALE	CH	17	2.74	108.0	20.0 $	25 B	0	200 $	.0040 $	250 $	75 $	.0050
80	PRE-GOLA I-SC-4	2256	SHALE	CH	17	2.74 $	97.0 $	28.0 $	18 B	0 $	80 $	.0040 $	180 $	75 $	.0050
81	PRE-GOLA I-SC-2	2243	SHALE	CH	17	2.74 $	96.0 $	27.0 $	11 B	0 $	90 $	.0040 $	112 $	75 $	.0050
82	PRE-GOLA I-SC-1	2256	SHALE	CH	17	2.74 $	100.0 $	26.0 $	12 B	0 $	100 $	.0040 $	125 $	75 $	.0050
83	PRE-GOLA I-SC-3	2263	SHALE	CH	17	2.74 $	105.0 $	25.0 $	16 B	0 $	130 $	.0040 $	140 $	75 $	.0050
84	TOBOGGAN-E1A $	4000	PLAYA	ML	7	2.56	61.6	9.0 $	3 B	0 $	25 $	.0040	221	30 $	.0700
85	TOBOGGAN-E1B $	4000	PLAYA	ML	7	2.56	61.6	9.0 $	3 B	0 $	25 $	.0040	221	30 $	.0700
86	TOBOGGAN-E1C $	4000	PLAYA	ML	7	2.56	61.6	9.0 $	3 B	0 $	25 $	.0040	221	30 $	.0700

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
76	33.0	33 $	.40	1.18 B	0 $	350000 $	125000	5870 $	4100	120.0	90.0	99 B	0 B	0	13
77	33.0	33 $	.40	1.18 B	0 $	350000 $	125000	5870 $	4100	127.0	100.0	99 B	0 B	0	13
78	33.0	33 $	.40	1.18 B	0 $	350000 $	125000 $	5870 $	4100	130.0	103.0	99 B	0 B	0	13
79	33.0	33 $	.40	1.18 B	0 $	350000 $	125000	5680 $	4000	120.0	92.0	99 B	0 B	0	13
80 $	12.0 $	1 $	.40	1.00 B	0 $	350000 $	125000 $	2620 $	1800	100.0	60.0	80 B	0 B	0	13
81 $	15.0 $	5 $	.40	1.00 B	0 $	350000 $	125000 $	3610 $	2500	100.0	60.0	80 B	0 B	0	13
82 $	17.0 $	10 $	.40	1.00 B	0 $	350000 $	125000 $	3670 $	2600	100.0	60.0	80 B	0 B	0	13
83 $	24.0 $	22 $	.40	1.00 B	0 $	350000 $	125000 $	4130 $	2500	100.0	60.0	80 B	0 B	0	13
84	48.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
85	48.0	5 $	.30 $	1.00 B	0 $	30000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
86	48.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

	SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS							
EVT NO.	SERIES/SHOT NAME		ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT		TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
87	TOBOGGAN-E2A	$	4000	PLAYA	ML	7	2.56	61.6	9.0	$	3 B	0 $	25 $	.0040	221	30 $	.0700
88	TOBOGGAN-E2B	$	4000	PLAYA	ML	7	2.56	61.6	9.0	$	3 B	0 $	25 $	.0040	221	30 $	.0700
89	TOBOGGAN-E2C	$	4000	PLAYA	ML	7	2.56	61.6	9.0	$	3 B	0 $	25 $	.0040	221	30 $	.0700
90	TOBOGGAN-E3A	$	4000	PLAYA	ML	7	2.61	61.7	9.3	$	4 B	0 $	25 $	.0040	205	30 $	.0700
91	TOBOGGAN-E3.5A	$	4000	PLAYA	ML	7	2.61	61.7	12.7	$	4 B	0 $	25 $	.0040	205	30 $	.0700
92	TOBOGGAN-E3B	$	4000	PLAYA	ML	7	2.61	61.7	9.3	$	4 B	0 $	25 $	.0040	205	30 $	.0700
93	TOBOGGAN-E3C	$	4000	PLAYA	ML	7	2.61	61.7	9.3	$	4 B	0 $	25 $	.0040	205	30 $	.0700
94	TOBOGGAN-E4A	$	4000	PLAYA	ML	7	2.56	61.8	9.6	$	5 B	0 $	23 $	.0040	188	30 $	.0700
95	TOBOGGAN-E4.5A	$	4000	PLAYA	ML	7	2.56	61.8	13.0	$	5 B	0 $	23 $	.0040	188	30 $	.0700
96	TOBOGGAN-E4B	$	4000	PLAYA	ML	7	2.56	61.8	9.6	$	5 B	0 $	23 $	.0040	188	30 $	.0700
97	TOBOGGAN-E4.5B	$	4000	PLAYA	ML	7	2.56	61.8	13.0	$	5 B	0 $	23 $	.0040	188	30 $	.0700

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
87	48.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
88	48.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
89	48.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
90	45.0	6 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
91	45.0	6 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
92	45.0	6 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
93	45.0	6 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
94	43.0	8 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
95	43.0	8 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
96	43.0	8 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
97	43.0	8 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS					STRENGTHS AND STRAINS					
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UWT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
98	TOBOGGAN-E4C $	4000	PLAYA	ML	7	2.56	61.8	9.6 $	5 B	0 $	23 $	.0040	188	30 $	.0700
99	TOBOGGAN-E5A $	4000	PLAYA	ML	7	2.56	61.8	9.6 $	4 B	0 $	20 $	.0040	164	30 $	.0500
100	TOBOGGAN-E5.5A $	4000	PLAYA	ML	7	2.56	61.8	13.0 $	4 B	0 $	20 $	.0040	164	30 $	.0500
101	TOBOGGAN-E5B $	4000	PLAYA	ML	7	2.56	61.8	9.6 $	4 B	0 $	20 $	.0040	164	30 $	.0500
102	TOBOGGAN-E5C $	4000	PLAYA	ML	7	2.56	61.8	9.6 $	4 B	0 $	20 $	.0040	164	30 $	.0500
103	TOBOGGAN-E6A $	4000	PLAYA	ML	7	2.57	61.0	8.1 $	3 B	0 $	16 $	.0040	131	30 $	.0400
104	TOBOGGAN-E6.5A $	4000	PLAYA	ML	7	2.57	61.0	11.6 $	3 B	0 $	16 $	.0040	131	30 $	.0400
105	TOBOGGAN-E6B $	4000	PLAYA	ML	7	2.57	61.0	8.1 $	3 B	0 $	16 $	.0040	131	30 $	.0400
106	TOBOGGAN-E6C $	4000	PLAYA	ML	7	2.57	61.0	8.1 $	3 B	0 $	16 $	.0040	131	30 $	.0400
107	TOBOGGAN-E7A $	4000	PLAYA	ML	7	2.57	61.0	11.6 $	3 B	0 $	14 $	.0040	122	30 $	.0400
108	MICE-S1(C1) $	2050	BASALT	ROCK	9	2.96	165.0 $	1.5 $	1600 B	0	5720 $	.0030 $	7000 $	100	.0035

ADDN STR-STN PARAMETERS					MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
98	43.0	8 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
99	37.0	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
100	37.0	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
101	37.0	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
102	37.0	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
103	32.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
104	32.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
105	32.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
106	32.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
107	29.0	5 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
108 $	30.0 $	1900 $	.29 $	1.40 B	0 $	5000000 $	2500000	11100 $	6900 B	0.0 B	0.0 $	98 B	0 B	0	15

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SF GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
109	MTCE-S2A	$ 2060	BASALT	ROCK	9	2.96	165.0 $	1.5 $	1600 B	0	5720 $	.0030 $	7000 $	100	.0035
110	MTCE-S3A	$ 2045	BASALT	ROCK	9	2.96	165.0 $	1.5 $	1600 B	0	5720 $	.0030 $	7000 $	100	.0035
111	MTCE-S4A	$ 2052	BASALT	ROCK	9	2.96	165.0 $	1.5 $	1600 B	0	5720 $	.0030 $	7000 $	100	.0035
112	MTCE-C2	$ 2055	BASALT	ROCK	9	2.96	165.0 $	1.5 $	1600 B	0	5720 $	.0030 $	7000 $	100	.0035
113	MTCE-LS	$ 2037	BASALT	ROCK	9	2.99	154.0 $	1.5 $	1600 B	0	5720 $	.0030 $	7000 $	100	.0035
132	ZULU II-M9	$ 1800	SAND	SP	4 $	2.65	111.2	5.5 $	2 B	0 $	10 $	.0075 $	77	14 $	.0100
133	ZULU II-M11	$ 1800	SAND	SP	4 $	2.65	110.6	6.3 $	2 B	0 $	9 $	.0075 $	74	14 $	.0100
134	ZULU II-M12	$ 1800	SAND	SP	4 $	2.65	110.6	5.6 $	2 B	0 $	9 $	.0075 $	70	14 $	.0100
135	ZULU II-M6	$ 1800	SAND	SP	4 $	2.65	109.9	5.5 $	2 B	0 $	8 $	.0075 $	63	14 $	.0100
136	ZULU II-M7	$ 1800	SAND	SP	4 $	2.65	113.6	6.1 $	2 B	0 $	14 $	.0075 $	110	14 $	.0100
137	ZULU II-M10	$ 1800	SAND	SP	4 $	2.65	110.6	6.0 $	2 B	0 $	9 $	.0075 $	74	14 $	.0100

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
109 $	30.0 $	1900 $	.25 $	1.40 B	0 $	5000000 $	2500000	11100 $	6900 B	0.0 B	0.0 $	98 B	0 B	0	15
110 $	30.0 $	1900 $	.25 $	1.40 B	0 $	5000000 $	2500000	11100 $	6900 B	0.0 B	0.0 $	98 B	0 B	0	15
111 $	30.0 $	1900 $	.25 $	1.40 B	0 $	5000000 $	2500000	11100 $	6900 B	0.0 B	0.0 $	98 B	0 B	0	15
112 $	30.0 $	1900 $	.25 $	1.40 B	0 $	5000000 $	2500000	11100 $	6900 B	0.0 B	0.0 $	98 B	0 B	0	15
113 $	30.0 $	1900 $	.25 $	1.40 B	0 $	5000000 $	2500000	11100 $	6900 B	0.0 B	0.0 $	98 B	0 B	0	15
132	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
133	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
134	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
135	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
136	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
137	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

	SHOT IDENT.		MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
138	ZULU II-M2	$ 1800	SAND	SP	4	$ 2.65	114.5	6.2 $	2 8	0 $	16	$ .0075 $	129	14	$ .0100
139	ZULU II-M4	$ 1800	SAND	SP	4	$ 2.65	110.4	6.1 $	2 8	0 $	9	$ .0075 $	74	14	$ .0100
140	ZULU II-M5	$ 1800	SAND	SP	4	$ 2.65	110.2	6.2 $	2 8	0 $	9	$ .0075 $	70	14	$ .0100
141	ZULU II-SS18	$ 1800	SAND	SP	4	$ 2.65	111.8	6.6 $	2 8	0 $	11	$ .0075	92	14	$ .0100
142	ZULU II-SS19	$ 1800	SAND	SP	4	$ 2.65	110.9	7.4 $	2 8	0 $	11	$ .0075 $	85	14	$ .0100
143	ZULU II-M1	$ 1800	SAND	SP	4	$ 2.65	110.2	6.0 $	2 8	0 $	9	$ .0075 $	70	14	$ .0100
144	ZULU II-M3	$ 1800	SAND	SP	4	$ 2.65	109.8	5.8 $	2 8	0 $	8	$ .0075 $	63	14	$ .0100
145	ZULU II-M8	$ 1800	SAND	SP	4	$ 2.65	110.7	5.8 $	2 8	0 $	9	$ .0075 $	74	14	$ .0100
146	ZULU II-SS17	$ 1800	SAND	SP	4	$ 2.65	111.8	6.6 $	2 8	0 $	11	$ .0075	92	14	$ .0100
147	ZULU II-SS20	$ 1800	SAND	SP	4	$ 2.65	111.8	7.6 $	2 8	0 $	12	$ .0075	96	14	$ .0100
148	ZULU II-15	$ 1800	SAND	SP	4	$ 2.65	114.3	6.1 $	2 8	0 $	16	$ .0075 $	125	14	$ .0100

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
138	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
139	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
140	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
141	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
142	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
143	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
144	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
145	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
146	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
147	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20
148	44.0	4	$ .32	$ 1.30 8	0 $	1240000 $	470000 $	1800 $	1100 8	0.0 8	0.0 8	0 8	0 8	0	20

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

EVT NO.	SHOT IDENT. SERIES/SHOT NAME	ELEV FT	MATERIAL MEDIUM	USCS CLASS	REF NO.	WT-VOL RELATIONSHIPS SP GR	DRY UNT LB/CUFT	MOIST PR CT	STRENGTHS AND STRAINS TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
149	ZULU II-8	$ 1800	SAND	SP	4 $	2.65	114.1	5.4 $	2 B	0 $	15 $	.0075 $	118	14 $	.0100
150	ZULU II-SS21	$ 1800	SAND	SP	4 $	2.65	112.2	7.6 $	2 B	0 $	11 $	.0075 $	88	14 $	.0100
151	ZULU II-10	$ 1800	SAND	SP	4 $	2.65	112.5	6.0 $	2 B	0 $	12 $	.0075	96	14 $	.0100
152	ZULU II-SS7	$ 1800	SAND	SP	4 $	2.65	110.8	6.0 $	2 B	0 $	9 $	.0075 $	74	14 $	.0100
153	ZULU II-1	$ 1800	SAND	SP	4 $	2.65	112.6	6.0 $	2 B	0 $	12 $	.0075	96	14 $	.0100
154	ZULU II-16	$ 1800	SAND	SP	4 $	2.65	115.6	6.0 $	2 B	0 $	20 $	.0075 $	158	14 $	.0100
155	ZULU II-19	$ 1800	SAND	SP	4 $	2.65	110.9	5.9 $	2 B	0 $	10 $	.0075 $	77	14 $	.0100
156	ZULU II-SS5	$ 1800	SAND	SP	4 $	2.65	109.7	7.0 $	2 B	0 $	9 $	.0075 $	70	14 $	.0100
157	ZULU II-SS10	$ 1800	SAND	SP	4 $	2.65	111.9	7.6 $	2 B	0 $	12 $	.0075	96	14 $	.0100
158	ZULU II-SS14	$ 1800	SAND	SP	4 $	2.65	111.6	7.7 $	2 B	0 $	12 $	.0075	96	14 $	.0100
159	ZULU II-SS16	$ 1800	SAND	SP	4 $	2.65	111.6	7.7 $	2 B	0 $	12 $	.0075	96	14 $	.0100

EVT NO.	AOON STR-STN PARAMETERS PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	MODULUS VALUES SECANT PSI	YOUNGS PSI	SHEAR PSI	WAVE VELOCITIES SEISMIC FPS	SHEAR FPS	ATTBRG LIMITS LL PR CT	PI PR CT	CORE RECOV PR CT	INTERNAL ENERGIES MELT MPSI/CIN	VAPOR MPSI/CIN	REMKS SEE NOTE
149	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
150	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
151	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
152	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
153	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
154	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
155	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
156	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
157	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
158	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
159	44.0	4 $	.32 $	1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
160	ZULU II-SS22	$ 1800	SAND	SP	4	$ 2.65	111.5	7.3 $	2 B	0 $	11	$ .0075	92	14	$ .0100
161	ZULU II-SS8	$ 1800	SAND	SP	4	$ 2.65	110.6	7.0 $	2 B	0 $	10	$ .0075 $	81	14	$ .0100
162	ZULU II-SS9	$ 1800	SAND	SP	4	$ 2.65	111.9	7.6 $	2 B	0 $	12	$ .0075	96	14	$ .0100
163	ZULU II-SS24	$ 1800	SAND	SP	4	$ 2.65	111.4	7.2 $	2 B	0 $	11	$ .0075 $	88	14	$ .0100
164	ZULU-1A	$ 3180	ALLUV	SP	28	$ 2.54	109.9	11.3 $	2 B	0 $	3	$ .0200	196	42	$ .0500
165	ZULU-1B	$ 3180	ALLUV	SP	28	$ 2.54	110.7	10.6 $	2 B	0 $	4	$ .0200	197	42	$ .0500
166	ZULU-1C	$ 3180	ALLUV	SP	28	$ 2.54	110.9	10.3 $	2 B	0 $	4	$ .0200	197	42	$ .0500
167	ZULU-2A	$ 3180	ALLUV	SP	28	$ 2.54	114.2	12.4 $	1 B	0 $	3	$ .0200	237	42	$ .0500
168	ZULU-2B	$ 3180	ALLUV	SP	28	$ 2.54	113.9	11.4 $	1 B	0 $	3	$ .0200	207	42	$ .0500
169	ZULU-3A	$ 3180	ALLUV	SP	28	$ 2.54	112.5	11.8 $	1 B	0 $	2	$ .0200	195	42	$ .0500
170	ZULU-3B	$ 3180	ALLUV	SP	28	$ 2.54	111.8	11.1 $	1 B	0 $	3	$ .0200	197	42	$ .0500

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
160	44.0	4	$ .32	$ 1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 P	0 B	0	20
161	44.0	4	$ .32	$ 1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 P	0 B	0	20
162	44.0	4	$ .32	$ 1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
163	44.0	4	$ .32	$ 1.30 B	0 $	1240000 $	470000 $	1800 $	1100 B	0.0 B	0.0 B	0 B	0 B	0	20
164	39.0	3	$ .40	$ 1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
165	39.0	3	$ .40	$ 1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
166	39.0	3	$ .40	$ 1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
167	41.0	2	$ .40	$ 1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
168	41.0	2	$ .40	$ 1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
169	40.0	2	$ .40	$ 1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
170	39.0	3	$ .40	$ 1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
171	ZULU-3C	$ 3180	ALLUV	SP	28	$ 2.54	113.8	10.9 $	1 B	0 $	4 $	.0200	211	42 $	.0500
172	ZULU-4C	$ 3180	ALLUV	SP	28	$ 2.54	115.3	11.3 $	1 B	0 $	4 $	.0200	224	42 $	.0500
173	ZULU-4B	$ 3180	ALLUV	SP	28	$ 2.54	115.2	11.4 $	1 B	0 $	4 $	.0200	224	42 $	.0500
174	ZULU-5A	$ 3180	ALLUV	SP	28	$ 2.54	103.9	9.6 $	1 B	0 $	4 $	.0200	190	42 $	.0500
175	ZULU-5B	$ 3180	ALLUV	SP	28	$ 2.54	105.7	9.6 $	1 B	0 $	4 $	.0200	190	42 $	.0500
176	ZULU-6A	$ 3180	ALLUV	SP	28	$ 2.54	109.4	8.9 $	1 B	0 $	4 $	.0200	197	42 $	.0500
177	ZULU-6B	$ 3180	ALLUV	SP	28	$ 2.54	10[illegible].2	9.1 $	1 B	0 $	4 $	.0200	190	42 $	.0500
178	ZULU-7A	$ 3180	ALLUV	SP	28	$ 2.54	107.2	9.3 $	1 B	0 $	4 $	.0200	190	42 $	.0500
179	ZULU-8C	$ 3180	ALLUV	SP	28	$ 2.54	105.7	9.3 $	1 B	0 $	4 $	.0200	190	42 $	.0500
180	ZULU-9A	$ 3180	ALLUV	SP	28	$ 2.54	107.2	9.8 $	1 B	0 $	4 $	.0200	190	42 $	.0500
181	ZULU-9C	$ 3180	ALLUV	SP	28	$ 2.54	105.9	9.6 $	1 B	0 $	4 $	.0200	197	42 $	.0500

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
171	41.0	3 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
172	42.0	3 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
173	42.0	3 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
174	39.0	2 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
175	39.0	2 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
176	39.0	3 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
177	39.0	2 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
178	39.0	2 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
179	39.0	2 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
180	39.0	2 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21
181	39.0	3 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 B	0 B	0	21

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.		MATERIAL				WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-O PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
182	ZULU-10A $	3180	ALLUV	SP	28 $	2.54	111.0	9.8 $	1 B	0 $	4 $	.0200	197	42 $	.0500
183	ZULU-10B $	3180	ALLUV	SP	28 $	2.54	112.4	10.5 $	1 B	0 $	4 $	.0200	197	42 $	.0500
184	ZULU-11A $	3180	ALLUV	SP	28 $	2.54	103.4	9.8 $	1 B	0 $	3 $	.0200 $	183	42 $	.0500
185	SANDIA-TUFF 1	5356	TUFF	ROCK	0 $	2.56 $	109.0 $	6.0 $	1400 B	0 $	15000 $	.0050 $	25000 $	200 $	.0090
186	SANDIA-TUFF 2	5348	TUFF	ROCK	0 $	2.56 $	109.0 $	6.0 $	1400 B	0 $	15000 $	.0050 $	25000 $	200 $	.0090
187	SANDIA-TUFF 6	5321	TUFF	ROCK	0 $	2.56 $	109.0 $	6.0 $	1400 B	0 $	15000 $	.0050 $	25000 $	200 $	.0090
188	SANDIA-TUFF 7	5317	TUFF	ROCK	0 $	2.56 $	109.0 $	6.0 $	1400 B	0 $	15000 $	.0050 $	25000 $	200 $	.0090
189	SANDIA-TUFF 11	5338	TUFF	ROCK	0 $	2.56 $	109.0 $	6.0 $	1400 B	0 $	15000 $	.0050 $	25000 $	200 $	.0090
200	AIR VENT I-1 $	3050	PLAYA	ML	18 $	2.56	87.4	15.9 $	4 B	0 $	25 $	.0040	205	30 $	.0700
201	AIR VENT II-1 $	3050	PLAYA	ML	18 $	2.56	84.1	16.1 $	4 B	0 $	25 $	.0040	205	30 $	.0700
202	AIR VENT II-2A $	3050	PLAYA	ML	18 $	2.56	84.1	16.1 $	4 B	0 $	25 $	.0040	205	30 $	.0700

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
182	39.0	3 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 P	0 B	0	21
183	39.0	3 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 P	0 B	0	21
184 $	39.0 $	2 $	.40 $	1.22 B	0 $	300000 $	110000 $	4200 $	2300 B	0.0 B	0.0 B	0 P	0 B	0	21
185 $	42.0 $	2000 $	.15 $	1.10 B	0 $	1400000 $	600000 $	5700 $	4000 B	0.0 B	0.0 $	70 P	0 B	0	22
186 $	42.0 $	2000 $	.15 $	1.10 B	0 $	1400000 $	600000 $	5700 $	4000 B	0.0 B	0.0 $	70 B	0 B	0	22
187 $	42.0 $	2000 $	.15 $	1.10 B	0 $	1400000 $	600000 $	5700 $	4000 B	0.0 B	0.0 $	70 P	0 B	0	22
188 $	42.0 $	2000 $	.15 $	1.10 B	0 $	1400000 $	600000 $	5700 $	4000 B	0.0 B	0.0 $	70 B	0 B	0	22
189 $	42.0 $	2000 $	.15 $	1.10 B	0 $	1400000 $	600000 $	5700 $	4000 B	0.0 B	0.0 $	70 B	0 B	0	22
200 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
201 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
202 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
203	AIR VENT II-2B	$ 3050	PLAYA	ML	18 $	2.56	84.1	16.1 $	4 B	0 $	25 $	.0040	205	30 $	.0700
204	AIR VENT II-3	$ 3050	PLAYA	ML	18 $	2.56	83.5	16.1 $	4 B	0 $	25 $	.0040	205	30 $	.0700
205	AIR VENT II-4	$ 3050	PLAYA	ML	18 $	2.56	82.5	16.0 $	4 B	0 $	25 $	.0040	205	30 $	.0700
206	AIR VENT II-5A	$ 3050	PLAYA	ML	18 $	2.56	80.5	15.9 $	4 B	0 $	25 $	.0040	205	30 $	.0700
207	AIR VENT II-5B	$ 3050	PLAYA	ML	18 $	2.56	80.5	15.9 $	4 B	0 $	25 $	.0040	205	30 $	.0700
208	AIR VENT II-6	$ 3050	PLAYA	ML	18 $	2.56	78.3	15.9 $	4 B	0 $	25 $	.0040	205	30 $	.0700
209	AIR VENT II-7A	$ 3050	PLAYA	ML	18 $	2.56	78.5	15.8 $	4 B	0 $	25 $	.0040	205	30 $	.0700
210	AIR VENT II-7B	$ 3050	PLAYA	ML	18 $	2.56	78.5	15.8 $	4 B	0 $	25 $	.0040	205	30 $	.0700
211	AIR VENT II-8	$ 3050	PLAYA	ML	18 $	2.56	80.3	15.4 $	4 B	0 $	25 $	.0040	205	30 $	.0700
212	AIR VENT II-9A	$ 3050	PLAYA	ML	18 $	2.56	82.1	15.0 $	4 B	0 $	25 $	.0040	205	30 $	.0700
213	AIR VENT II-9B	$ 3050	PLAYA	ML	18 $	2.56	79.3	16.8 $	4 B	0 $	25 $	.0040	205	30 $	.0700

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
203	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
204	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
205	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
206	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
207	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
208	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
209	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
210	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
211	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
212	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
213	$ 29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
214	AIR VENT II-10A $	3050	PLAYA	ML	18 $	2.56	81.5	17.3 $	4 B	0 $	25 $	.0040	205	30 $	.0700
215	AIR VENT II-10B $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	14.8 $	4 B	0 $	25 $	.0040	205	30 $	.0700
216	AIR VENT II-11A $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	14.8 $	4 B	0 $	25 $	.0040	205	30 $	.0700
217	AIR VENT II-11B $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	14.8 $	4 B	0 $	25 $	.0040	205	30 $	.0700
218	AIR VENT II-12 $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	14.8 $	4 B	0 $	25 $	.0040	205	30 $	.0700
219	AIR VENT II-13 $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	14.8 $	4 B	0 $	25 $	.0040	205	30 $	.0700
220	AIR VENT II-14 $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	14.8 $	4 B	0 $	25 $	.0040	205	30 $	.0700
221	AIR VENT III-1A $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	20.6 $	4 B	0 $	25 $	.0040	205	30 $	.0700
222	AIR VENT III-1B $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	20.6 $	4 B	0 $	25 $	.0040	205	30 $	.0700
223	AIR VENT III-1C $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	20.6 $	4 B	0 $	25 $	.0040	205	30 $	.0700
224	AIR VENT III-1D $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	20.6 $	4 B	0 $	25 $	.0040	205	30 $	.0700

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		RMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
214 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
215 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
216 $	9.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
217 $	9.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
218 $	9.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
219 $	9.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
220 $	9.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
221 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
222 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
223 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
224 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14

TABLE 3. CATALOGED MATERIAL PROPERTY DATA (CONTINUED)

SHOT IDENT.			MATERIAL			WT-VOL RELATIONSHIPS			STRENGTHS AND STRAINS						
EVT NO.	SERIES/SHOT NAME	ELEV FT	MEDIUM	USCS CLASS	REF NO.	SP GR	DRY UNT LB/CUFT	MOIST PR CT	TNSLE-S PSI	TNSLE-D PSI	UNC COMP PSI	FLE STN IN/IN	CONF COMP PSI	CNF PRES PSI	FLE STN IN/IN
225	AIR VENT III-2A $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	20.6 $	4 B	0 $	25 $	.0040	205	30 $	.0700
226	AIR VENT III-2B $	3050	PLAYA	ML	18 $	2.56 $	89.9 $	20.6 $	4 B	0 $	25 $	.0040	205	30 $	.0700
227	AIR VENT III-2C $	3050	PLAYA	ML	18 $	2.56 $	83.3 $	20.6 $	4 B	0 $	25 $	.0040	205	30 $	.0700
228	AIR VENT III-3A $	3050	PLAYA	ML	18 $	2.56 $	83.3 $	20.6 $	4 B	0 $	25 $	.0040	205	30 $	.0700
229	AIR VENT III-3B $	3050	PLAYA	ML	18 $	2.56 $	83.3 $	20.6 $	4 B	0 $	25 $	.0040	205	30 $	.0700
502	FLAT TOP I	4625	LIMESTN	ROCK	58	2.71	167.9	.2	635 B	0 B	0	80.0000 B	0 B	0	80.0000
503	FLAT TOP II	3075	PLAYA	SM	58	2.56	70.2	14.1 $	4 B	0 $	25 $	.0040	205	30 $	.0700
504	FLAT TOP III	3077	PLAYA	SM	58	2.56	71.0	25.7 $	4 B	0 $	25 $	.0040	205	30 $	.0700

	ADDN STR-STN PARAMETERS				MODULUS VALUES			WAVE VELOCITIES		ATTBRG LIMITS			INTERNAL ENERGIES		REMKS
EVT NO.	PHI DEG	COHESION PSI	POISN RATIO	BULK FACTOR	SECANT PSI	YOUNGS PSI	SHEAR PSI	SEISMIC FPS	SHEAR FPS	LL PR CT	PI PR CT	CORE RECOV PR CT	MELT MPSI/CIN	VAPOR MPSI/CIN	SEE NOTE
225 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
226 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
227 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
228 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
229 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
502 $	45.0 B	0	.30 B	0.00 B	0	10540000	4200000 $	16000	10800 B	0.0 B	0.0 B	0 B	0 B	0	
503 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14
504 $	29.0 $	7 $	.30 $	1.00 B	0 $	38000 $	15000 $	4000 $	2500 B	0.0 B	0.0 $	70 B	0 B	0	14

1 INTERNAL ENERGIES ESTIMATED BASED ON REF. 26.

2 GEOPHYSICAL DATA FRAM REF. 56.

3 GEOPHYSICAL DATA FRAM REF. 57.

4 MATERIAL PROPERTY DATA ALSO FROM REF. 34.

5 PREDOMINATELY SP-SM BUT ALSO INCLUDES GP-GM.

6 BULKING FACTOR FROM REF. 23.

7 UNAVAILABLE MATERIAL PROP. DATA ESTIMATED USING REFS. 53, 69 AND 86.

8 UNAVAILABLE MATERIAL PROP. DATA ESTIMATED USING REF. 69.

9 UNAVAILABLE MATERIAL PROP. DATA ESTIMATED USING REFS. 28, 53, 69 AND 86.

10 ESTIMATED VALUES BASED ON REFS. 28 AND 69.

11 ESTIMATED VALUES BASED ON REF. 2.

12 DATA ALSO OBTAINED FROM REF. 35.

13 GEOPHYSICAL MEASUREMENTS FROM REF. 68.

14 ESTIMATED VALUES BASED ON REF. 64.

15 ESTIMATED VALUES BASED ON REF. 2.

16-18. NOTE NUMBERS NOT USED.

19 VOLUME CALCULATED USING- VOL = 0.45(PI)(R)(R)(D).

20 ESTIMATED VALUES BASED ON REF. 81.

21 ESTIMATED VALUES BASED ON REF. 69.

22 ESTIMATED VALUES BASED ON REF. 72.

APPENDIX II

THE COMPUTER PROGRAM

<u>Description of the Program Elements.</u> Considerable time and effort was expended in developing the program and its formats. Therefore it seems appropriate to include it as an appendix. A brief description of its essential features follows.

Main Program. - This portion of the program is nothing more than a calling program, i.e., it calls the various main subroutines to read, sort and print the data and to perform the surface fit of selected data.

Subroutine REDATA. - This subroutine reads and stores all crater and material property data into the computer data banks. Six cards are read for each cratering event. In addition, any note cards associated with an event are also read and stored.

Subroutine PRDATA and Related HEAD Subroutines. - This subroutine prints all crater and material property data along with calling the related CDHEAD, MPHEAD1 and MPHEAD2 subroutines to provide the necessary headings for the output data. This subroutine produces the cataloged data listing.

Subroutine SURFIT. - This subroutine is the main program for the conduct of the least squares surface fit and analysis. It primarily calls the various subroutines necessary to perform the surface fit and analysis. It also specifies the dependent

variable (radius, depth or volume), the scaling exponent and the number of independent variables to be used in the surface fitting process. In addition, it calls for or specifies printing of all pertinent matrices and coefficients.

Subroutine EQN. -This subroutine determines the type regression and the independent variables to be used in the least squares surface fit. It develops the vector of observations and the matrix of measured independent variables and normalizes these matrices to provide better matrix inversion and manipulation.

Subroutine CORCO. - This subroutine develops a simple correlation matrix between all the variables involved in the surface fit; dependent as well as independent.

Subroutine COEFF. - This subroutine takes the vector of observations and the matrix of measured independent variables and generates the vector and x-coefficient matrices. These latter matrices are, in essence, the normal equations which must be solved simultaneously to obtain the regression coefficients.

Subroutine ABPRN. - This subroutine prints the coefficients of the prediction equation. It also prints the decoded form of these coefficients when the model used was either a three or four parameter bell curve.

Subroutine PREDIC. - This subroutine calculates the estimated value of the dependent variable for each observation using the empirical equation generated and compares this value

with the actual. It also calculates the multiple correlation coefficient and standard deviation for all the data being considered.

Subroutine MATINV. - This subroutine inverts the x-coefficient matrix to be used in solving the normal equations.

Subroutine MATPRN. - This subroutine prints a square matrix. It is used to print the x-coefficient matrix as well as the unit matrix which should result when the x-coefficient matrix and the inverse of the x-coefficient matrix are multiplied together.

Subroutines SIMALT and MULT. - These subroutines multiply a square matrix times a column matrix and a square matrix times another square matrix respectively. They are used to multiply the inverse of the x-coefficient matrix times the vector matrix to obtain the coefficients of the curve fit and to multiply the x-coefficient matrix times its inverse.

Typical Program. - A computer printout of the program as it was run during the latter stages of the research follows.

Sample Data Output. - The computer output for a simple regression analysis of scaled radius as a function of scaled depth of burst and one material property, total unit weight, using the skewed bell curve model follows the program.

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,PUNCH,TAPE7=
     *PUNCH)
C  MAIN PROGRAM
C
      CALL REDATA (NDATA)
      CALL SURFIT(NDATA)
      STOP
      END
C*********************************************************************
      SUBROUTINE REDATA(NDATA)
C  THIS SUBROUTINE READS ALL CRATER AND MATERIAL PROPERTY DATA FOR EACH
C  CRATERING EVENT.  SIX CARDS ARE READ FOR EACH EVENT(ITEM NO.) ALONG
C  WITH ANY REMARKS(NOTE) CARDS.  A BLANK CARD MUST BE INSERTED BETWEEN
C  DATA CARDS AND NOTE CARDS AND AT THE END OF THE NOTE CARDS.
      COMMON          W(200,28),SHOT(200,4),SITE(200,2),DATE(200,2),
     *EMED(200,2),EXTYPE(200),YIELD(200,3),TNTWT(200),DOB(200),
     *RADIUS(200),DEPTH(200),VOL(200),HTLIP(200),
     *RMKCD(200),ELEV(200),CLASS(200,2)
      COMMON SPGR(200),UWT(200),PMOIST(200),SPTEN(200),DITEN(200),
     *UCOMP(200),UCSTN(200),CCOMP(200),CONFP(200),CCSTN(200),PHI(200),
     *COHES(200),POISN(200),BULK(200),SECMOD(200),YOUMOD(200),
     *SHEMOD(200),SEIVEL(200),SHEVOL(200),ATTLL(200),
     *ATTPI(200),CORE(200),EMELT(200),VAPOR(200),RMKMP(200,2)
      COMMON INO(200),NREF(200),ISL(200),MREF(200)
      COMMON /NOTE/ NCARD(100),RNTE(100),TEXT(100,19)
      I=0
  100 I=I+1
      READ(5,10)INO(I),NREF(I),(SHOT(I,J),J=1,4),(SITE(I,J),J=1,2),
     *(DATE(I,J),J=1,2),(EMED(I,J),J=1,2),EXTYPE(I),(YIELD(I,J),J=1,3),
     *TNTWT(I)
      IF(INO(I).EQ.0)GO TO 200
      READ(5,20)DOB(I),RADIUS(I),DEPTH(I),VOL(I),W(I,1),ISL(I),W(I,2),
     *HTLIP(I),RMKCD(I)
      READ(5,30)W(I,3),ELEV(I),(CLASS(I,J),J=1,2),MREF(I),W(I,4),
     *SPGR(I),W(I,5),UWT(I),W(I,6),PMOIST(I)
      READ(5,40)W(I,7),SPTEN(I),W(I,8),DITEN(I),W(I,9),UCOMP(I),W(I,10),
     *UCSTN(I),W(I,11),CCOMP(I),W(I,12),CONFP(I),W(I,13),CCSTN(I)
      READ(5,50)W(I,14),PHI(I),W(I,15),COHES(I),W(I,16),POISN(I),
     *W(I,17),BULK(I),W(I,18),SECMOD(I),W(I,19),YOUMOD(I),W(I,20),
     *SHEMOD(I)
      READ(5,60)W(I,21),SEIVEL(I),W(I,22),SHEVOL(I),W(I,23),
     *W(I,24),ATTLL(I),W(I,25),ATTPI(I),W(I,26),CORE(I),W(I,27),
     *EMELT(I),W(I,28),VAPOR(I),(RMKMP(I,J),J=1,2)
   10 FORMAT(1X,2I4,6A4,2A3,2A4,2X,3A4,A2,F13.2)
   20 FORMAT(5X,3F8.2,F13.2,A2,I3,A2,F6.2,A4)
   30 FORMAT(21X,A2,F6.0,8X,2A3,I4,A2,F5.2,A2,F6.1,A2,F5.1)
   40 FORMAT(5X,2(A2,F6.0),A2,F7.0,A2,F6.4,A2,F8.0,A2,F7.0,A2,F6.4)
   50 FORMAT(5X,A2,F5.1,A2,F7.0,A2,F4.2,A2,F5.2,3(A2,F9.0))
   60 FORMAT(5X,2(A2,F7.0),A2,7X,2(A2,F5.1),A2,F4.0,A2,F6.0,A2,F7.0,A4,A
     *3)
      GO TO 100
  200 NDATA=I-1
      J=0
  300 J=J+1
      READ(5,70)NCARD(J),RNTE(J),(TEXT(J,K),K=1,19)
   70 FORMAT(I1,F4.0,18A4,A3)
      IF(NCARD(J).NE.0)GO TO 300
      RETURN
      END
C*********************************************************************
```

```
      SUBROUTINE PRDATA(NDATA)
C  THIS SUBROUTINE PRINTS ALL DATA READ INTO THE COMPUTER BY THE REDATA
C  SUBROUTINE.
      COMMON          W(200,28),SHOT(200,4),SITE(200,2),DATE(200,2),
     *EMED(200,2),EXTYPE(200),YIELD(200,3),TNTWT(200),DOB(200),
     *RADIUS(200),DEPTH(200),VOL(200),HTLIP(200),
     *RMKCD(200),ELEV(200),CLASS(200,2)
      COMMON SPGR(200),UWT(200),PMOIST(200),SPTEN(200),DITEN(200),
     *UCOMP(200),UCSTN(200),CCOMP(200),CONFP(200),CCSTN(200),PHI(200),
     *COHES(200),POISN(200),BULK(200),SECMOD(200),YOUMOD(200),
     *SHEMOD(200),SEIVEL(200),SHEVOL(200),ATTLL(200),
     *ATTPI(200),CORE(200),EMELT(200),VAPOR(200),RMKMP(200,2)
      COMMON INO(200),NREF(200),ISL(200),MREF(200)
      COMMON /NOTE/ NCARD(100),RNTE(100),TEXT(100,19)
      I=0
  100 CALL COHEAD
      NLINES=7
  200 I=I+1
      WRITE(6,10)INO(I),NREF(I),(SHOT(I,J),J=1,4),(SITE(I,J),J=1,2),
     *(DATE(I,J),J=1,2),(EMED(I,J),J=1,2),EXTYPE(I),(YIELD(I,J),J=1,3),
     *TNTWT(I),DOB(I),RADIUS(I),DEPTH(I),VOL(I),W(I,1),ISL(I),W(I,2),
     *HTLIP(I),RMKCD(I)
      IF(I.EQ.NDATA)GO TO 300
      NLINES=NLINES+2
      IF(NLINES.EQ.59)GO TO 100
      GO TO 200
  300 I=0
  400 CALL MPHED1
      NLINES=8
      K=0
  500 I=I+1
      K=K+1
      WRITE(6,20)INO(I),(SHOT(I,J),J=1,4),W(I,3),ELEV(I),
     *(EMED(I,J),J=1,2),(CLASS(I,J),J=1,2),MREF(I),W(I,4),SPGR(I),
     *W(I,5),UWT(I),W(I,6),PMOIST(I),W(I,7),SPTEN(I),W(I,8),DITEN(I),
     *W(I,9),UCOMP(I),W(I,10),UCSTN(I),W(I,11),CCOMP(I),W(I,12),
     *CONFP(I),W(I,13),CCSTN(I)
      IF(I.EQ.NDATA)GO TO 550
      NLINES=NLINES+2
      IF(NLINES.LT.30)GO TO 500
  550 CALL MPHED2
      NLINES=NLINES+7
      I=I-K
  560 I=I+1
      WRITE(6,30)INO(I),W(I,14),PHI(I),W(I,15),COHES(I),W(I,16),POISN(I)
     *,W(I,17),BULK(I),W(I,18),SECMOD(I),W(I,19),YOUMOD(I),W(I,20),
     *SHEMOD(I),W(I,21),SEIVEL(I),W(I,22),SHEVOL(I),
     *W(I,24),ATTLL(I),W(I,25),ATTPI(I),W(I,26),CORE(I),W(I,27),
     *EMELT(I),W(I,28),VAPOR(I),(RMKMP(I,J),J=1,2)
      IF(I.EQ.NDATA)GO TO 600
      NLINES=NLINES+2
      IF(NLINES.EQ.59)GO TO 400
      GO TO 560
  600 J=0
      IF(NCARD(J+1).EQ.0)GO TO 700
  620 WRITE(6,40)
      NLINES=2
  630 J=J+1
```

```
      IF(NCARD(J).GT.1)GO TO 650
      WRITE(6,50)RNTE(J),(TEXT(J,K),K=1,19)
      NLINES=NLINES+2
      GO TO 670
  650 WRITE(6,60)(TEXT(J,K),K=1,19)
      NLINES=NLINES+1
  670 IF(NCARD(J+1).EQ.0)GO TO 700
      IF(NLINES.GE.60)GO TO 620
      GO TO 630
  700 WRITE(6,70)NDATA
   10 FORMAT(*0*,2I4,6A4,2A3,2A4,2X,3A4,A2,F13.2,3F8.2,F13.2,A2,I3,A2,F6
     *.2,A4)
   20 FORMAT(*0*,I4,4A4,A2,F6.0,2A4,2A3,I4,A2,F5.2,A2,F6.1,A2,F5.1,2(A2,
     *F6.0),A2,F7.0,A2,F6.4,A2,F8.0,A2,F7.0,A2,F6.4)
   30 FORMAT(*0*,I4,A2,F5.1,A2,F7.0,A2,F4.2,A2,F5.2,3(A2,F9.0),2(A2,F7.0
     *),2(A2,F5.1),A2,F4.0,2(A2,F7.0),A4,A3)
   40 FORMAT(*1*,36X,*N O T E S*)
   50 FORMAT(*0*,F4.0,18A4,A3)
   60 FORMAT(* *,4X,18A4,A3)
   70 FORMAT(*1*,*THE NUMBER OF DATA ITEMS =*,I5)
      RETURN
      END
C*********************************************************************

      SUBROUTINE COHEAD
C   THIS SUBROUTINE PRINTS THE HEADINGS FOR THE CRATER DATA LISTING.
      WRITE(6,10)
   10 FORMAT(*1*,53X,*C R A T E R     D A T A*//18X,*IDENTIFICATION*,24X,
     **EXPLOSIVE DATA*,8X,*DEPTH*,10X,*APPARENT CRATER DIMENSIONS*,7X,*
     *RMK*/2X,*---------------------------------------------   ---------
     *----------------     0-   -------------------------------------
     *- ---*)
      WRITE(6,20)
   20 FORMAT(* *,* EVT REF   SERIES/SHOT*,5X,*SITE   DATE  MEDIUM  TYPE
     *  YIELD*,5X,*EQUIV HT    BURST   RADIUS  DEPTH*,5X,*VOLUME     SLP
     *  LIP HT SEE*/2X,*NO. NO.*,7X,*NAME*,14X,*MO YR*,28X,*LBS-TNT
     * FT       FT       FT*,7X,*CU FT      DEG     FT   NTE*/2X,*--- --- --
     *------------- -------- ----- --------  ---- ---------- ------------ -
     *------ ------- -------- ------------ ---- -------- ---*)
      RETURN
      END
C*********************************************************************
```

```
      SUBROUTINE MPHED1
C   THIS SUBROUTINE PRINTS THE HEADINGS FOR THE FIRST HALF OF THE MATERIAL
C   PROPERTY LISTING
      WRITE(6,30)
   30 FORMAT('1',43X,'M A T E R I A L    P R O P E R T Y    D A T A'//,'
     *                          '/10X,'SHOT IDENT.',14X,'MATERIAL',6X,'W
     *T-VOL RELATIONSHIPS',20X,'STRENGTHS AND STRAINS'/2X,'-------------
     *-------------- ----------------- -------------------- -----------
     *---------------------------------------------')
      WRITE(6,40)
   40 FORMAT(' ',' EVT   SERIES/SHOT',5X,'ELEV   MEDIUM  USCS REF  SP GR
     * DRY UWT  MOIST TNSLE-S TNSLE-D UNC COMP FLE STN CONF COMP CNF PRE
     *S FLE STN'/2X,'NO.',7X,'NAME',9X,'FT',11X,'CLASS NO.',8X,'LB/CUFT
     * PR CT   PSI      PSI',6X,'PSI     IN/IN      PSI',7X,'PSI     IN/IN'/
     *2X,'--- -------------- ------- ------- ----- --- ------ ------- -
     *----- ------- ------- -------- ------- --------- -------- -------'
     *)
      RETURN
      END
C*********************************************************************

      SUBROUTINE MPHED2
C   THIS SUBROUTINE PRINTS THE HEADINGS FOR THE SECOND HALF OF THE MATERIAL
C   PROPERTY DATA
      WRITE(6,50)
   50 FORMAT('0','                          '/9X,'ADDN STR-STN PARAMETERS
     *',13X,'MODULUS VALUES',10X,'WAVE VELOCITIES',2X,'ATTBRG LIMITS',5X
     *,'  INTERNAL ENERGIES  REMKS'/'  --- --------------------------
     *------------------------------ ---------------- ------------
     *CORE ----------------- ------')
      WRITE(6,60)
   60 FORMAT(' ',' EVT   PHI  COHESION POISN  BULK    SECANT     YOUNGS'
     *,6X,'SHEAR     SEISMIC   SHEAR     LL      PI',3X,'RECOV',3X,'MELT
     *  VAPOR    SEE'/' NO.   DEG      PSI   RATIO FACTOR      PSI ',7X,'
     *PSI',8X,'PSI',7X,'FPS       FPS',4X,'PR CT  PR CT PR CT MPSI/CIN MP
     *SI/CIN  NOTE'/2X,'--- ------ -------- ----- ------ ---------- ----
     *------ ---------- -------- -------- ------ ------ ----- -------- -
     *------- ------')
      RETURN
      END
C*********************************************************************
```

```
      SUBROUTINE SURFIT(ND)
C  THIS SUBROUTINE DOES A LEAST SQUARES SURFACE FIT FOR RADIUS, DEPTH, AND
C  VOLUME OF THE APPARENT CRATER
      DIMENSIONSEC(200),LX(41),LY(41),AU(200,40),COL(200),XMEAN(40),
     *VECT(40),XKOEF(40,40),XK(1600),B(40),
     *HOLXK(40,40),R(40,40),UMAT(40,40),DVAR(3)
      COMMON DUM(200,78),INO(200),IDUM(200,3)
      COMMON /AYE/ UAN(40),ANS(40),EXPO
      EQUIVALENCE (XKOEF,XK)
      DATA BB,CC,DD,EE,SMAL/4HXKOF,4HPRNT,4HUNIT,4HCORR,1.E-06/
      DATA DVAR/6HRADIUS,6H DEPTH,6HVOLUME/
C  M=1 FOR RADIUS, 2 FOR DEPTH, 3 FOR VOLUME
C  L=1 FOR EXPO=0.250, 2 FOR 0.292, 3 FOR 0.3125, 4 FOR 0.333, 5 FOR VAR EXPO.
C  KK=1 FOR 3 PARAMETER EQN., 2 FOR 4 PARS., 3 AND 4 FOR 2 MAT. PROPS.,
C      5 AND 6 FOR 3 MAT. PROPS., 7, 8, 9, AND 10 FOR 4 MAT. PROPS.
      DO 900 M=1,3
      L=3
      DO 900 KK=4,10
      IF(KK.EQ.6.OR.KK.EQ.7)GO TO 900
      CALL EQN(COL,AU,ND,NP,L,CNORM,XMEAN,R,SEC,KK,M)
   33 WRITE(6,1)EXPO,DVAR(M)
    1 FORMAT(*1*,*EXPONENT=*,F6.4,*    FOR   *,A6,*  EVALUATION*)
      CALL MATPRN(R,NP,EE,CC)
      CALL COEFF(COL,AU,VECT,XKOEF,ND,NP,M)
      WRITE(6,2)
    2 FORMAT(*1*/* PRESENT CONTENTS OF  VECT  MATRIX*/)
      WRITE(6,5)(COL(I),I=1,NP)
    5 FORMAT(*0*,F12.4)
      CALL MATPRN(XKOEF,NP,BB,CC)
      DO 100 I=1,NP
      DO 100 J=1,NP
      HOLXK(I,J)=XKOEF(I,J)
  100 CONTINUE
      CALL MATINV(XK,LX,LY,NP,40,SMAL)
      CALL MULT(UMAT,XKOEF,HOLXK,NP)
      CALL MATPRN(UMAT,NP,DD,CC)
  150 CALL SIMALT(XKOEF,VECT,ANS,NP)
      WRITE(6,8)
    8 FORMAT(*1*/* NORM. COEFS. OF THE PREDICTION EQUATION*)
      DO 200 K=1,NP
 200  WRITE(6,10) K,ANS(K)
   10 FORMAT(*0*,*N(*,I2,*)=*,F19.10)
      DO 90 K=1,NP
   90 UAN(K)=ANS(K)/XMEAN(K)*CNORM
      CALL ABPRN(UAN,NP,KK)
      CALL PREDIC(COL,AU,ANS,INO,ND,NP,M,CNORM,SEC)
  900 CONTINUE
      RETURN
      END
C*** *****************************************************************
```

```
      SUBROUTINE EQN(COL,AU,ND,NP,  L,CNORM,XMEAN,R,SEC,KK,M)
C   THIS SUBROUTINE DETERMINES THE TYPE REGRESSION AND VARIABLES TO BE
C   USED IN THE LEAST SQUARES SURFACE FIT AND DEVELOPS THE AU ARRAY
      DIMENSION COL(ND),AU(ND,40),XMEAN(40),R(40,40)
      REAL  MED
      DIMENSION  MED(200),TYPE(6),SEC(ND)
      DATA TYPE/3H  R,3H SP,3H  S,3H  H,3H  C,3H CH/
      COMMON           W(200,28),SHOT(200,4),SITE(200,2),DATE(200,2),
     *EMED(200,2),EXTYPE(200),YIELD(200,3),TNTWT(200),DOB(200),
     *RADIUS(200),DEPTH(200),VOL(200),HTLIP(200),
     *RMKCD(200),ELEV(200),CLASS(200,2)
      COMMON SPGR(200),UWT(200),PMOIST(200),SPTEN(200),DITEN(200),
     *UCOMP(200),UCSTN(200),CCOMP(200),CONFP(200),CCSTN(200),PHI(200),
     *COHES(200),POISN(200),BULK(200),SECMOD(200),YOUMOD(200),
     *SHEMOD(200),SEIVEL(200),SHEVOL(200),ATTLL(200),
     *ATTPI(200),CORE(200),EMELT(200),VAPOR(200),RMKHP(200,2)
      COMMON INO(200),NREF(200),ISL(200),MREF(200)
      COMMON /AYE/ UAN(40),ANS(40),EXPO
      CNORM=0.0
      GO TO(30,31,32,33,34),L
   30 EXPO=1./4.
      GO TO 40
   31 EXPO=7./24.
      GO TO 40
   32 EXPO=5./15.
      GO TO 40
   33 EXPO=1./3.
      GO TO 40
   34 EXPO=1.0
   40 CONTINUE
      DO 50 J= 1,ND
   43 WUWT = ((1.+PMOIST(J)/100.)*UWT(J))/62.43
      SHUWT=WUWT**(EXPO)
      SIG=1.0-(UWT(J)/62.43)*((1.0/SPGR(J))+PMOIST(J)/100.)
      IF(SIG.LT.0.0) SIG=0.0
      VMOIST=PMOIST(J)*UWT(J)/6243.
      PROS=SIG+VMOIST
      VOURAT=PROS/(1.0-PROS)
      DESAT=VMOIST/PROS
      GO TO (210,220,230),M
 210  Y=RADIUS(J)        /TNTWT(J)**(EXPO)
      GO TO 250
 220  Y=DEPTH(J)         /TNTWT(J)**(EXPO)
      GO TO 250
  230 IF(VOL(J).LE.0.0) VOL(J)=0.0
      Y=VOL(J)**(1./3.)/TNTWT(J)**(EXPO)
 250  X= DOB(J)          /TNTWT(J)**(EXPO)
      IF(Y.LE.0.000)Y= .01
      IF(X.LE.0.000)X=.01
      YY=ALOG(Y)
      XX=ALOG(X+1.0)
      COL(J)=YY
      CNORM=CNORM+COL(J)/ND
      GO TO (110,120,130,135,140,140,150,150,150,150),KK
  110 AU(J,1)=COL(J)
      AU(J,2)=X
      AU(J,3)=X*X
      NP=3
```

```
      GO TO 50
  120 AU(J,1)=COL(J)
      AU(J,2)=X
      AU(J,3)=X*X
      AU(J,4)=X**3
      NP=4
      GO TO 50
  130 AU(J,1)=1.0
      AA=SHUHT
      BB=DESAT
      AU(J,2)=AA
      AU(J,3)=BB
      AU(J,4)=AA**2
      AU(J,5)=BB**2
      AU(J,6)=AA*BB
      NMP=6
      GO TO 180
  135 AU(J,1)=1.0
      AU(J,2)=SHUHT
      NMP=2
      GO TO 180
  140 AU(J,1)=1.0
      AA=SHUHT
      BB=DESAT
      CC=SPGR(J)
      AU(J,2)=AA
      AU(J,3)=BB
      AU(J,4)=CC
      AU(J,5)=AA**2
      AU(J,6)=BB**2
      AU(J,7)=CC**2
      AU(J,8)=AA*BB
      AU(J,9)=AA*CC
      AU(J,10)=BB*CC
      NMP=10
      GO TO 180
  150 AU(J,1)=1.0
      AA=SHUHT
      BB=DESAT
      CC=SPGR(J)
      PHE=PHI(J)/180.0*3.141593
      IF(KK.EQ.9)CC=TAN(PHE)
      IF(KK.EQ.10)CC=SEIVEL(J)**(1./3.)
      AU(J,2)=AA
      AU(J,3)=BB
      AU(J,4)=CC
      AU(J,5)=AA**2
      AU(J,6)=VAPOR(J)
      AU(J,7)=CC**2
      AU(J,8)=AA*BB
      AU(J,9)=AA*CC
      AU(J,10)=BB*CC
      NMP=10
  180 MS=NMP+1
      NP=NMP*3
      DO 300 MM=MS,NP
  300 AU(J,MM)=AU(J,MM-NMP)*X
      IF(KK.EQ.3.OR.KK.EQ.5)GO TO 47
```

```
      IF(KK.EQ.7)GO TO 47
      MS=NP+1
      MF=NP+NMP
      DO 400MM=MS,MF
  400 AU(J,MM)=AU(J,MM-NP)*X**3
      NP=NP+NMP
   47 AU(J,1)=COL(J)
   50 SEC(J)=DOB(J)/TNTWT(J)**(EXPO)
   55 DO 60 K=1,ND
      COL(K)=COL(K)/CNORM
   60 CONTINUE
      DO 70 J=1,NP
      XMEAN(J)=0.0
      DO 70 I=1,ND
      XMEAN(J)=XMEAN(J)+AU(I,J)/ND
   70 CONTINUE
      DO 80 J=1,NP
      DO 80 I=1,ND
      AU(I,J)=AU(I,J)/XMEAN(J)
   80 CONTINUE
      CALL CORCO(AU,R,ND,NP)
      DO 85 K=1,ND
   85 AU(K,1)=1.0
      XMEAN(1)=1.0
  100 RETURN
      END
C*****************************************************************************
      SUBROUTINE CORCO(X,R,ND,NC)
      DIMENSION  X(ND,40),R(40,40)
      DO 100 I=1,NC
      DO 100 J=1,NC
  100 R(I,J)=0.0
      DO 400 J=1,NC
      DO 400 I=J,NC
      TOPC=0.0
      TOPI=0.0
      TOPJ=0.0
      BOTI=0.0
      BOTJ=0.0
      DO 300 K=1,ND
      TOPC=TOPC+X(K,I)*X(K,J)
      TOPI=TOPI+X(K,I)
      TOPJ=TOPJ+X(K,J)
      BOTI=BOTI+X(K,I)**2
      BOTJ= BOTJ+X(K,J)**2
  300 CONTINUE
      R(I,J)=(TOPC-TOPI/ND*TOPJ)/ SQRT((BOTI-TOPI/ND*TOPI)*(BOTJ-TOPJ/ND
     **TOPJ))
      R(J,I)=R(I,J)
  400 CONTINUE
      RETURN
      END
C*****************************************************************************
```

```
      SUBROUTINE ABPRN(UAN,NP,KK)
      DIMENSION UAN(40),B(40),B4(2)
      WRITE(6,8)
    8 FORMAT('1'/' COEFFICIENTS OF THE PREDICTION EQUATION')
      DO 200 K=1,NP
  200 WRITE(6,10) K,UAN(K)
   10 FORMAT(' ','C(',I2,')=',F19.10)
      GO TO (310,320,800,800,800,800,800,800,800,800),KK
  310 B(1)= EXP(UAN(1)- UAN(2)**2/(4.0*UAN(3)))
      B(2)=UAN(3)
      B(3)=UAN(2)/(2*UAN(3))
      WRITE(6,88)
   88 FORMAT('0'/' COEFFICIENTS OF THE PREDICTION EQUATION')
      DO 101 MM=1,NP
  101 WRITE(6,11) MM,B(MM)
   11 FORMAT('0','B(',I2,')=',F19.10)
      GO TO 800
  320 B(2) =UAN(4)
      BT=UAN(3)/UAN(4)
      BP= ABS(BT)
      UNRAD=BP**2.0-(3.0*UAN(2)/UAN(4))
      IF(UNRAD.GE.0.0)GO TO 755
      WRITE(6,700) UNRAD
  700 FORMAT('0','UNRAD=',F20.10)
      UNRAD=0.0
  755 BSQT= SQRT(UNRAD)
      B4(1)=(BT+BSQT)/3.0
      B4(2)=(BT-BSQT)/3.0
      DO 900 JJ=1,2
  813 B(4)=B4(JJ)
  812 B(3)=BT-(2.0*B(4))
      BNEG= ABS(B(4))
      B(1)= EXP(UAN(1)- B(2)*B(3)*BNEG**2)
      WRITE(6,55)
   55 FORMAT('0'/' COEFFICIENTS OF THE PREDICTION EQUATION')
      DO 191 MMM=1,NP
  191 WRITE(6,22) MMM,B(MMM)
   22 FORMAT('0','B(',I2,')=',F19.10)
  900 CONTINUE
  800 RETURN
      END
C*******************************************************************
      SUBROUTINE COEFF(COL,AU,VECT,XKOEF,ND,NP,M)
C  THIS SUBROUTINE GENERATES AND ASSEMBLES THE VECT AND XKOEF MATRICES
      DIMENSION COL(ND),AU(ND,40),VECT(40),XKOEF(40,40)
      ADATA=ND
      DO 10 I=1,NP
      VECT(I)=0.
   10 CONTINUE
      DO 30 I=1,NP
      DO 25 J=1,ND
      VECT(I)=VECT(I)+COL(J)*AU(J,I)
   25 CONTINUE
      VECT(I)=VECT(I)/ADATA
   30 CONTINUE
      DO 20 J=1,NP
      DO 20 K=1,NP
      XKOEF(J,K)=0.0
   20 CONTINUE
```

```
      DO 40 I=1,NP
      DO 40 J=1,NP
      DO 35 K=1,ND
      XKOEF(I,J)=AU(K,I)*AU(K,J)+XKOEF(I,J)
   35 CONTINUE
      XKOEF(I,J)=XKOEF(I,J)/ADATA
   40 CONTINUE
   50 RETURN
      END
C*********************************************************************
      SUBROUTINE PREDIC(COL,AU,ANS,IEV,ND,NP,M,CNORM,SEC)
C  THIS SUBROUTINE CALCULATES THE RADIUS, DEPTH, OR VOLUME USING THE
C  EMPIRICAL EQUATION GENERATED AND COMPARES THESE VALUES WITH THE ACTUAL.
      DIMENSION IEV(ND),COL(ND),AU(ND,40),ANS(NP),DVAR(3),SEC(ND),PAR(2)
      DATA DVAR/6HRADIUS,6H DEPTH,6HVOLUME/
      WRITE(6,10)DVAR(M)
   10 FORMAT(*1*,A6,* PREDICTION AND EVALUATION*)
      WRITE(6,20)
   20 FORMAT(*-*,10X,*PREDICTED VALUE*,12X,*ACTUAL VALUE*,12X,*PERCENT E
     *RROR*,12X,*RESIDUAL*, 9X,*EVENT NO.*,6X,*SC 000*)
      CMEAN=0.0
      DO 90 I=1,ND
   90 CMEAN=CMEAN+ EXP(COL(I)*CNORM)
      RTOP=0.0
      RBOT=0.0
      NLINES=0
      DO 200 I=1,ND
      PREVAL    =0.0
      DO 100 J=1,NP
      PREVAL=PREVAL+AU(I,J)*ANS(J)
  100 CONTINUE
      PREVAL=PREVAL*CNORM
      ACTVAL=COL(I)*CNORM
      PREVAL= EXP(PREVAL)
      ACTVAL= EXP(ACTVAL)
      IF(ACTVAL.EQ.0.0)ACTVAL=1.0E-3
      RESID=PREVAL-ACTVAL
      ERROR=RESID/ACTVAL*100.0
      WRITE(6,30)PREVAL,ACTVAL,ERROR,RESID,IEV(I),SEC(I)
   30 FORMAT(* *,6X,F17.6,8X,F17.6,15X,F8.2,6X,F17.6,9X,I5,2X,F15.4)
      RTOP=RTOP+(PREVAL-CNORM)**2
      RBOT=RBOT+(ACTVAL-CNORM)**2
      NLINES=NLINES+1
      IF(NLINES.LT.50)GO TO 200
      NLINES=0
      WRITE(6,50)
   50 FORMAT(*1*)
  200 CONTINUE
      RSQ=RTOP/RBOT*100.
      S=SQRT(RBOT/(ND-1))
      WRITE(6,40)RSQ,DVAR(M),S
   40 FORMAT(*0*,*MULT CORR COEF =*,F9.2/* STAND. DEVIATION FOR *,A6,*=*
     *,F12.4)
      RETURN
      END
C*********************************************************************
```

```
      SUBROUTINE MATINV (A,IROW,ICOL,NP,NDIM,SMLST)
      DIMENSION A(1600),IROW(41),ICOL(41)
      N=NP
      NP1=N+1
      DO 5 I=1,N
      ICOL(I)=I
    5 IROW(I)=I
      DO 75 ITER=1,N
      MAXR=ITER
      MAXC=1
      TEMP= ABS(A(MAXR))
      LIMITC=NP1-ITER
      DO 15 I=ITER,N
      DO 15 J=1,LIMITC
      IJ=(J-1)*NDIM+I
      IF (TEMP-( ABS(A(IJ)))) 10,15,15
   10 MAXR=I
      MAXC=J
      TEMP= ABS(A(IJ))
   15 CONTINUE
      SMLST=-0.0
      IF (TEMP-SMLST) 20,20,25
   20 IROW(NP1)=ITER
      WRITE(6,200)
  200 FORMAT('0','THIS IS A SINGULAR MATRIX AND IT WILL NOT INVERT')
   25 IF (MAXR-ITER) 30,40,30
   30 DO 35 J=1,N
      MAXRJ=(J-1)*NDIM+MAXR
      ITJ=(J-1)*NDIM+ITER
      TEMP=A(MAXRJ)
      A(MAXRJ)=A(ITJ)
   35 A(ITJ)=TEMP
      ITEMP=IROW(MAXR)
      IROW(MAXR)=IROW(ITER)
      IROW(ITER)=ITEMP
   40 IF (MAXC-1) 45,55,45
   45 DO 50 I=1,N
      IMAXC=(MAXC-1)*NDIM+I
      TEMP=A(I)
      A(I)=A(IMAXC)
   50 A(IMAXC)=TEMP
      ITEMP=ICOL(MAXC)
      ICOL(MAXC)=ICOL(1)
      ICOL(1)=ITEMP
   55 TEMP=A(ITER)
      ITEMP=ICOL(1)
      DO 60 J=2,N
      ITJM1=(J-2)*NDIM+ITER
      ITJ=(J-1)*NDIM+ITER
      A(ITJM1)=A(ITJ)/TEMP
   60 ICOL(J-1)=ICOL(J)
      ITN=(N-1)*NDIM+ITER
      A(ITN)=1.0/TEMP
      ICOL(N)=ITEMP
      DO 75 I=1,N
      IF (I-ITER) 65,75,65
   65 TEMP=A(I)
      DO 70 J=2,N
```

```
      IJM1=(J-2)*NDIM+I                                                 GUNA 192
      IJ=(J-1)*NDIM+I                                                   GUNA 193
      ITJM1=(J-2)*NDIM+ITER                                             GUNA 194
      A(IJM1)=A(IJ)-A(ITJM1)*TEMP                                       GUNA 195
   70 CONTINUE                                                          GUNA 196
      IN=(N-1)*NDIM+I                                                   GUNA 197
      ITN=(N-1)*NDIM+ITER                                               GUNA 198
      A(IN)=-(TEMP*A(ITN))                                              GUNA 199
   75 CONTINUE                                                          GUNA 200
      DO 100 I=1,N                                                      GUNA 201
      DO 80 J=I,N                                                       GUNA 202
      IF (IROW(J)-I) 80,85,80                                           GUNA 203
   80 CONTINUE                                                          GUNA 204
   85 IF (I-J) 90,100,90                                                GUNA 205
   90 DO 95 L=1,N                                                       GUNA 206
      LI=(I-1)*NDIM+L                                                   GUNA 207
      LJ=(J-1)*NDIM+L                                                   GUNA 208
      TEMP=A(LI)                                                        GUNA 209
      A(LI)=A(LJ)                                                       GUNA 210
   95 A(LJ)=TEMP                                                        GUNA 211
      IROW(J)=IROW(I)                                                   GUNA 212
  100 CONTINUE                                                          GUNA 213
      DO 125 I=1,N                                                      GUNA 214
      DO 105 J=I,N                                                      GUNA 215
      IF (ICOL(J)-I) 105,110,105                                        GUNA 216
  105 CONTINUE                                                          GUNA 217
  110 IF (I-J) 115,125,115                                              GUNA 218
  115 DO 120 L=1,N                                                      GUNA 219
      IL=(L-1)*NDIM+I                                                   GUNA 220
      JL=(L-1)*NDIM+J                                                   GUNA 221
      TEMP=A(IL)                                                        GUNA 222
      A(IL)=A(JL)                                                       GUNA 223
  120 A(JL)=TEMP                                                        GUNA 224
      ICOL(J)=ICOL(I)                                                   GUNA 225
  125 CONTINUE                                                          GUNA 226
      IROW(NP1)=0                                                       GUNA 227
      RETURN                                                            GUNA 228
      END                                                               GUNA 229
C*********************************************************************
      SUBROUTINE MATPRN ( A , NP, B ,  RITE )
      DIMENSION A(40,40)
      N=NP
    5 FORMAT ('0'//)
   10 FORMAT('0',11(E12.3))
   22 FORMAT  ('1' , 24H PRESENT CONTENTS OF            , A4 ,          SUP 1277
     * 12H    MATRIX      , / )
      DATA YAZ/4HPRNT/
      IF  (  RITE  .NE.  YAZ  )   GO TO  620                            SUP 1280
      WRITE (6,22) B                                                    SUP 1285
      IF ( N.GT.11 ) GO TO 60                                           SUP 1286
      DO 50 I=1,NP
      WRITE (6,10) (A(I,J),J=1,NP)
   50  CONTINUE                                                         SUP 1289
      GO TO 500                                                         SUP 1290
   60 N1 = N/11*11-10
```

```
      DO 200  K = 1 , M1 , 11                                           SUP 1292
      KK = K + 10                                                       SUP 1293
      DO 100  I = 1 , N                                                 SUP 1294
      WRITE (6,10) ( A(I,J) , J=K  ,  KK)                               SUP 1295
  100  CONTINUE                                                         SUP 1296
      WRITE(6,5)                                                        SUP 1297
  200  CONTINUE                                                         SUP 1299
      K=K+11
      DO 300  I = 1 , N                                                 SUP 1300
      WRITE (6,1J) ( A(I,J) , J=K  ,  N )                               SUP 1301
  300  CONTINUE                                                         SUP 1302
  600 CONTINUE                                                          SUP 1304
  500 RETURN
      END                                                               SUP 1306
C***********************************************************************
      SUBROUTINE SIMALT (A,B,C,NP)
      DIMENSION A(40,40), B(40),C(40)
      M=NP
      N=NP
      DO 200  I = 1 , M                                                 GUNA 124
      C(I)  =  0.0                                                      GUNA 125
  200 CONTINUE                                                          GUNA 126
      DO 500  I = 1 , M                                                 GUNA 127
      DO  400  J = 1 , N                                                GUNA 128
      C(I)  =  C(I)  +  A(I,J) * B(J)                                   GUNA 129
  400 CONTINUE                                                          GUNA 130
  500 CONTINUE                                                          GUNA 131
      RETURN                                                            GUNA 132
      END                                                               GUNA 133
C***********************************************************************
      SUBROUTINE MULT(A,B,C,NP)
      DIMENSION A(40,40),B(40,40),C(40,40)
      K=NP
      M=NP
      N=NP
      DO 100 I=1,K                                                      QUAR 723
      DO 200 J=1,N                                                      QUAR 724
      Q = 0.0                                                           QUAR 725
      DO 300 L=1,M                                                      QUAR 726
      Q = Q + B(I,L)*C(L,J)                                             QUAR 727
  300 CONTINUE                                                          QUAR 728
      A(I,J) =  Q                                                       QUAR 729
  200 CONTINUE                                                          QUAR 730
  100 CONTINUE                                                          QUAR 731
      RETURN
      END
```

EXPONENT= .3125 FOR RADIUS EVALUATION

PRESENT CONTENTS OF CORR MATRIX

1.000E+00	9.366E-02	2.386E-01	2.479E-01	-8.998E-02	-8.376E-02	-2.672E-01	-2.645E-01
9.366E-02	1.000E+00	7.294E-02	1.492E-01	3.637E-02	7.182E-02	5.418E-03	2.125E-02
2.386E-01	7.294E-02	1.000E+00	9.954E-01	9.105E-01	9.123E-01	7.757E-01	7.777E-01
2.479E-01	1.492E-01	9.954E-01	1.000E+00	9.017E-01	9.081E-01	7.649E-01	7.690E-01
-8.998E-02	3.637E-02	9.105E-01	9.017E-01	1.000E+00	9.988E-01	9.631E-01	9.637E-01
-8.376E-02	7.182E-02	9.123E-01	9.081E-01	9.988E-01	1.000E+00	9.600E-01	9.618E-01
-2.672E-01	5.418E-03	7.757E-01	7.649E-01	9.631E-01	9.600E-01	1.000E+00	9.997E-01
-2.645E-01	2.125E-02	7.777E-01	7.690E-01	9.637E-01	9.618E-01	9.997E-01	1.000E+00

PRESENT CONTENTS OF VECT MATRIX

1.9235

2.0027

1.9650

2.1795

1.8762

1.5921

-.4348

.9378

PRESENT CONTENTS OF XKOF MATRIX

1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
1.000E+00	1.005E+00	1.004E+00	1.009E+00	1.003E+00	1.007E+00	1.001E+00	1.003E+00
1.000E+00	1.004E+00	1.529E+00	1.528E+00	1.840E+00	1.836E+00	2.169E+00	2.162E+00
1.000E+00	1.008E+00	1.528E+00	1.532E+00	1.835E+00	1.834E+00	2.156E+00	2.153E+00
1.000E+00	1.003E+00	1.840E+00	1.835E+00	2.610E+00	2.596E+00	3.532E+00	3.514E+00
1.000E+00	1.007E+00	1.836E+00	1.834E+00	2.596E+00	2.586E+00	3.505E+00	3.490E+00
1.000E+00	1.001E+00	2.169E+00	2.156E+00	3.532E+00	3.505E+00	5.293E+00	5.258E+00
1.000E+00	1.003E+00	2.162E+00	2.153E+00	3.514E+00	3.490E+00	5.258E+00	5.226E+00

PRESENT CONTENTS OF UNIT MATRIX

1.000E+00	0.	-8.731E-11	5.821E-11	0.	1.746E-10	2.328E-10	2.328E-10
0.	1.000E+00	1.746E-10	2.910E-11	1.164E-10	0.	0.	0.
2.328E-10	0.	1.000E+00	0.	-9.313E-10	-9.313E-10	-3.725E-09	1.863E-09
0.	0.	-9.313E-10	1.000E+00	1.863E-09	1.863E-09	1.863E-09	-1.863E-09
0.	-1.863E-09	-3.725E-09	-1.863E-09	1.000E+00	0.	3.725E-09	-3.725E-09
0.	9.313E-10	3.725E-09	1.863E-09	1.863E-09	1.000E+00	0.	0.
0.	-4.657E-10	1.863E-09	9.313E-10	0.	0.	1.000E+00	1.863E-09
-4.657E-10	-9.313E-10	-2.794E-09	-1.863E-09	0.	1.863E-09	1.863E-09	1.000E+00

```
NORM. COEFS. OF THE PREDICTION EQUATION

N( 1)=        .7698767454

N( 2)=       -.6415280693

N( 3)=      -6.1078288335

N( 4)=       3.4334176744

N( 5)=      14.6954181885

N( 6)=     -16.4834946622

N( 7)=      -9.7545907023

N( 8)=      10.3837296572


COEFFICIENTS OF THE PREDICTION EQUATION

C( 1)=        .4043436035
C( 2)=       -.2818015115
C( 3)=      -2.4577916237
C( 4)=       2.0275170733
C( 5)=       2.9637168585
C( 6)=      -2.7711614984
C( 7)=       -.8190957313
C( 8)=        .7079614133
```

PREDICTED VALUE	ACTUAL VALUE	PERCENT ERROR	RESIDUAL	EVENT NO.	SC DOB
2.118614	2.746192	-22.85	-.627578	80	1.3675
2.151307	2.862814	-24.85	-.711507	76	1.5129
2.143946	2.806797	-23.62	-.662851	77	1.6537
2.130136	3.060042	-30.39	-.929906	81	1.7710
2.110891	2.678867	-21.20	-.567976	78	1.8555
2.075493	2.295499	-9.58	-.220005	79	2.0053
2.034677	.795835	155.67	1.238842	82	2.1409
1.885515	1.636506	15.22	.249008	83	2.6117
1.082035	1.122532	-3.61	-.040497	40	0.0000
1.082035	1.514976	-28.58	-.432942	34	0.0000
1.082035	1.474318	-26.61	-.392283	35	0.0000
1.089137	.813448	33.89	.275689	501	.0233
1.214966	1.467247	-17.19	-.252281	45	.1467
1.214966	1.599829	-24.06	-.384863	39	.1467
1.234142	1.308503	-5.68	-.074357	8	.1724
1.356185	1.670540	-18.82	-.314355	38	.2917
1.356185	1.626346	-16.61	-.270161	47	.2917
1.609117	1.476085	9.01	.133031	37	.5621
1.609117	1.741250	-7.59	-.132134	48	.5621
1.609117	1.873833	-14.13	-.264716	43	.5621
1.660735	1.837959	-9.64	-.177224	11	.6224
1.686510	1.480938	13.88	.205572	7	.6796
1.837771	1.953382	-5.92	-.115612	44	.8432
2.009834	1.997577	.61	.012258	36	1.1225
2.009834	2.077126	-3.24	-.067292	46	1.1225
2.009834	2.068287	-2.83	-.058453	42	1.1225
2.009834	2.321078	-13.41	-.311244	15	1.1225
2.064236	2.135584	-3.34	-.071348	12	1.2464
2.144702	1.548217	38.53	.596486	5	1.6170
2.140054	2.530850	-15.44	-.390796	49	1.6724
2.139675	2.059093	3.91	.080582	9	1.6735
2.140047	2.351876	-9.01	-.211829	50	1.6799
2.140114	2.499622	-14.38	-.359509	16	1.6847
2.140114	2.672864	-19.93	-.532750	13	1.6847
2.123632	2.435279	-12.80	-.311648	51	1.8544
2.075317	2.334740	-11.11	-.259423	52	2.0331
2.027101	2.593305	-21.83	-.566205	59	2.1509
2.017726	2.475961	-18.51	-.458235	58	2.1709
2.010168	2.309158	-12.95	-.298991	55	2.1864
1.996771	2.302522	-13.28	-.305751	53	2.2131
1.993536	2.376297	-16.11	-.382761	57	2.2194
1.993536	2.544431	-21.65	-.550895	56	2.2194
1.985906	2.368808	-16.16	-.382901	17	2.2451
1.985906	2.508461	-20.83	-.522555	21	2.2451
1.950366	2.596850	-24.89	-.646483	33	2.3158
1.896038	2.196990	-13.70	-.300952	54	2.3866
1.639143	2.001112	-18.09	-.361970	14	2.8107
1.614164	2.492551	-35.24	-.878387	32	2.8461
1.576342	2.526139	-37.60	-.949797	31	2.8931
1.557770	2.076465	-24.98	-.518695	10	2.9143

PREDICTED VALUE	ACTUAL VALUE	PERCENT ERROR	RESIDUAL	EVENT NO.	SC DOB
1.243985	1.780141	-30.12	-.536157	30	3.3588
1.237709	1.004092	23.27	.233617	22	3.3676
1.237709	1.654630	-25.20	-.416921	19	3.3676
1.157141	1.437195	-19.49	-.280054	29	3.4825
.830899	.776350	7.07	.054850	28	3.9952
.762233	.535633	42.30	.226599	27	4.1189
.582112	.738927	-21.22	-.156814	20	4.4901
.574497	.415425	38.29	.159072	26	4.5078
1.073309	1.234518	-13.06	-.161209	133	0.0000
1.073994	1.326646	-13.04	-.252653	134	0.0000
1.073531	1.363498	-21.27	-.289967	132	0.0000
1.548659	1.907054	-18.79	-.358396	136	.4606
1.540451	2.100524	-26.66	-.560072	137	.4606
1.537202	2.155800	-28.69	-.618599	135	.4606
1.937166	2.349270	-17.54	-.412103	138	.9213
1.922339	2.340057	-17.85	-.417718	140	.9213
1.922673	2.432185	-20.95	-.509512	139	.9213
2.101404	2.330844	-9.84	-.229440	142	1.2898
2.101537	2.404547	-12.60	-.303009	141	1.2898
2.119412	2.266354	-6.48	-.146942	144	1.3819
2.120739	2.340057	-9.37	-.219318	145	1.3819
2.120310	2.422972	-12.49	-.302662	143	1.3819
2.138462	2.349270	-8.97	-.210808	147	1.4741
2.137450	2.367695	-9.72	-.230245	146	1.4741
2.143915	2.275567	-5.79	-.131652	149	1.6122
2.144195	2.303206	-6.90	-.159011	148	1.6122
2.142136	2.220290	-3.52	-.078[illegible]	150	1.6583
2.122117	2.091311	1.47	.030806	151	1.8241
2.121033	1.833352	15.69	.287678	152	1.8334
2.118330	2.082098	1.74	.036232	158	1.8426
2.119316	2.008395	5.52	.110921	156	1.8426
2.119293	2.063672	2.70	.055621	155	1.8426
2.118330	2.247929	-5.77	-.129599	159	1.8426
2.117521	2.220290	-4.63	-.102769	154	1.8426
2.118622	2.072885	2.21	.045736	153	1.8426
2.118257	2.192652	-3.39	-.074395	157	1.8426
2.116702	1.907054	10.99	.209648	160	1.8518
2.095556	1.888629	10.96	.206928	163	1.9439
2.095184	1.685947	24.27	.409237	162	1.9439
2.095967	2.017608	3.88	.078359	161	1.9439
1.035188	.771247	34.22	.263941	111	0.0000
1.035188	.801198	29.21	.233990	109	0.0000
1.035188	.906028	14.26	.129160	108	0.0000
1.035188	.853613	21.27	.181575	110	0.0000
1.042845	.907934	14.86	.134911	113	0.0000
1.256854	1.048297	19.89	.208558	112	.1647
1.777351	1.732173	2.61	.045178	63	.5543
1.767339	1.824556	-3.14	-.057216	67	.5543
2.064136	1.628516	26.75	.435620	68	.9299
2.142892	1.928486	11.12	.214406	62	1.1086

PREDICTED VALUE	ACTUAL VALUE	PERCENT ERROR	RESIDUAL	EVENT NO.	SC DOB
2.171915	1.637468	32.64	.534447	74	1.4847
2.164354	1.506768	43.64	.657586	6	1.5490
2.165760	2.078409	4.20	.087350	63	1.5570
2.138261	1.807234	18.32	.331027	61	1.6975
2.138006	1.953891	9.42	.184115	65	1.6975
2.118447	1.741729	21.63	.376718	72	1.7044
2.053007	1.790521	14.66	.262487	71	2.0646
2.034238	1.232152	65.10	.802085	64	2.1479
2.037732	1.343216	51.71	.694516	70	2.1462
1.536155	1.759649	-12.70	-.223494	179	.4606
1.567672	1.971544	-20.49	-.403872	173	.4606
1.531955	1.989370	-23.02	-.458015	174	.4606
1.929205	2.026821	-4.82	-.097616	176	.9213
1.922788	2.072885	-7.24	-.150097	178	.9213
2.119270	2.100524	.89	.018746	181	1.3819
2.118963	2.257142	-6.12	-.138179	175	1.3819
2.142012	2.192652	-2.31	-.050639	184	1.6122
2.119466	1.999182	6.02	.120284	177	1.8426
2.119201	1.989970	6.49	.129231	180	1.8426
2.117747	2.220290	-4.62	-.102543	182	1.8426
2.117556	2.211077	-4.23	-.093521	165	1.8426
2.117594	2.155800	-1.77	-.038206	160	1.8426
2.117596	2.284740	-7.32	-.167144	164	1.8426
2.116421	2.229503	-5.07	-.113082	169	1.8426
2.116049	2.321631	-8.86	-.205582	168	1.8426
2.116950	2.349270	-9.89	-.232320	170	1.8426
2.115568	2.340057	-9.59	-.224489	172	1.8426
2.115557	2.441398	-13.35	-.325841	167	1.8426
2.116277	2.422972	-12.66	-.306696	171	1.8426
1.034682	.984510	5.10	.050172	502	0.0000
2.072423	2.068287	.20	.004136	187	1.2233
2.096239	1.548739	35.35	.547499	1	1.2906
2.098621	2.651650	-20.86	-.553029	185	1.3028
2.141995	2.050610	4.46	.091385	189	1.6476
2.139082	2.457196	-12.95	-.318114	186	1.7006
2.169630	1.484946	46.11	.684684	2	1.4133
2.151900	2.140241	.54	.011659	75	1.6119
2.091604	.810739	157.99	1.280865	3	1.9060
1.081640	.888764	21.70	.192876	223	0.0000
1.081640	.929658	16.35	.151982	221	0.0000
1.081640	.929658	16.35	.151982	222	0.0000
1.081640	.959647	12.71	.121993	224	0.0000
1.092193	.954594	14.41	.137599	203	0.0000
1.092193	.979343	11.52	.112850	202	0.0000
1.089348	1.030066	5.76	.059283	227	0.0000
1.081640	1.080876	.07	.000764	225	0.0000
1.081640	1.168639	-7.44	-.086999	226	0.0000
1.089348	1.084500	.45	.004848	228	0.0000
1.089348	1.155745	-5.74	-.066396	229	0.0000
1.101058	1.422070	-22.57	-.321011	504	0.0000

PREDICTED VALUE	ACTUAL VALUE	PERCENT ERROR	RESIDUAL	EVENT NO.	SC DOB
1.111492	1.312680	-15.33	-.201188	503	0.0000
1.217545	1.187939	2.49	.029605	204	.1534
1.327690	1.347038	-1.44	-.019348	205	.2811
1.562209	1.502602	3.97	.059607	207	.5621
1.562209	1.562706	-.03	-.000497	206	.5621
1.643195	1.736019	-5.35	-.092824	200	.6268
1.773327	1.693521	4.71	.079806	208	.8415
1.960220	1.735947	12.92	.224272	209	1.1225
1.960220	1.757160	11.56	.203059	210	1.1225
2.091433	1.824335	14.64	.267098	211	1.4036
2.139909	1.948079	9.85	.191830	213	1.6847
2.139934	1.941008	10.25	.198926	212	1.6847
1.127969	.683999	64.91	.443970	86	0.0000
1.127969	.767541	46.96	.360428	85	0.0000
1.127969	.809312	39.37	.318657	84	0.0000
1.267006	1.174808	7.85	.092198	88	.2611
1.267006	1.331449	-4.84	-.064443	87	.2611
1.267006	1.268793	-.14	-.001786	89	.2611
1.441149	1.409770	2.23	.031380	93	.5221
1.441149	1.451541	-.72	-.010391	90	.5221
1.441149	1.576853	-8.61	-.135704	92	.5221
1.642907	1.488090	10.40	.154817	91	.7832
1.829067	1.790930	2.13	.038137	94	1.0443
1.829067	1.858807	-1.60	-.029741	96	1.0443
1.829067	1.916242	-4.55	-.087176	98	1.0443
2.004529	1.728273	15.98	.276256	97	1.3053
2.004529	1.958013	2.38	.046516	95	1.3053
2.114432	1.911021	10.64	.203411	102	1.5664
2.114432	1.921464	10.04	.192968	99	1.5664
2.114432	2.088548	1.24	.025885	101	1.5664
2.141007	1.649953	29.76	.491055	100	1.8275
2.058433	.783205	162.82	1.275228	105	2.0885
2.058433	.992060	107.49	1.066373	103	2.0885
2.058433	1.253129	64.26	.805304	106	2.0885

MULT CORR COEF = 88.49
STAND. DEVIATION FOR RADIUS= 1.3909

APPENDIX III

DATA AND PREDICTION CURVE PLOTS

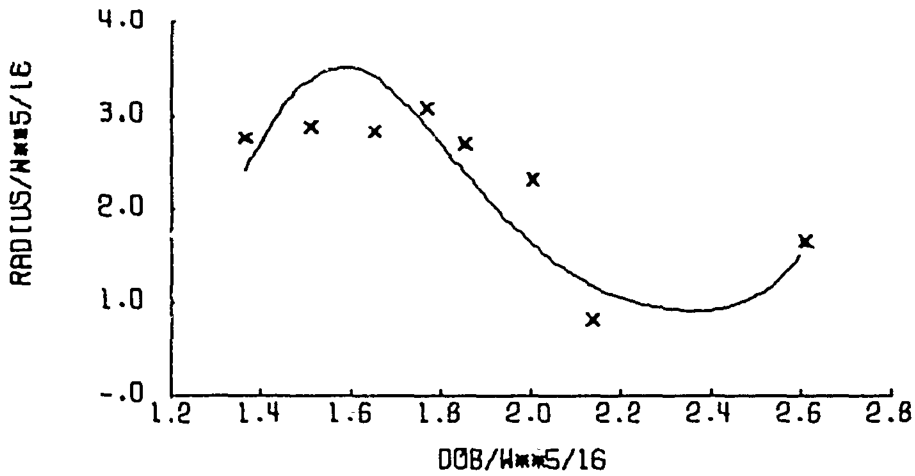


FIG. 5. CRATER RADIUS AS A FUNCTION OF CHARGE DEPTH FOR CLAY SHALE

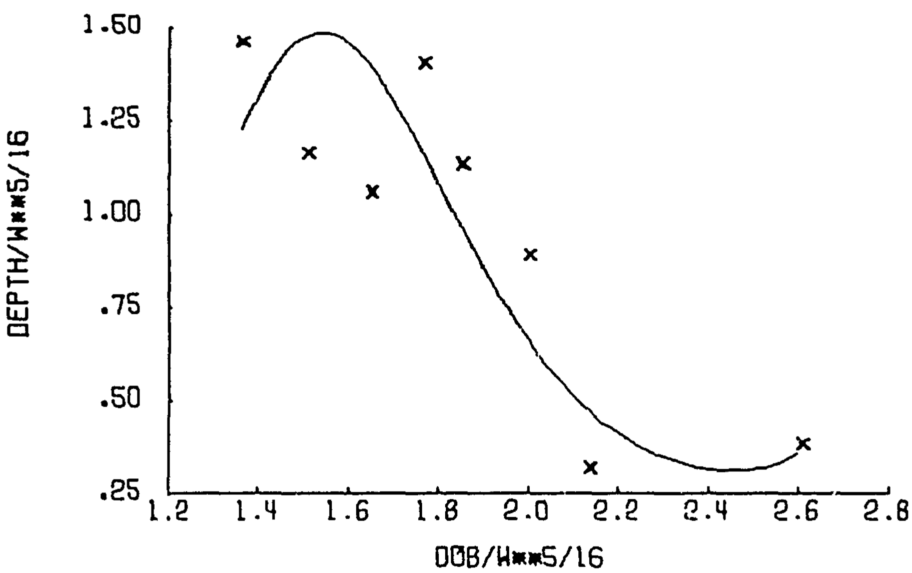


FIG. 6. CRATER DEPTH AS A FUNCTION OF CHARGE DEPTH FOR CLAY SHALE

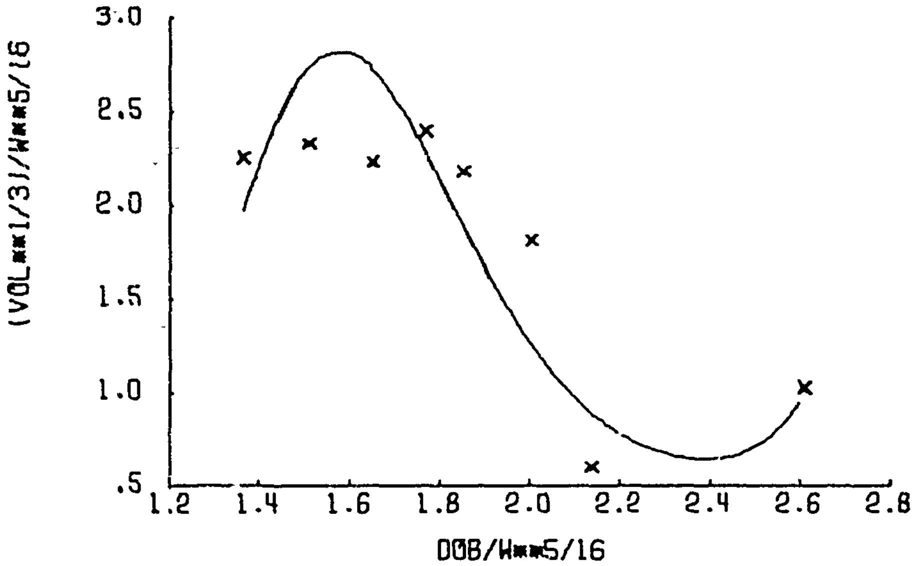


FIG. 7. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH FOR CLAY SHALE

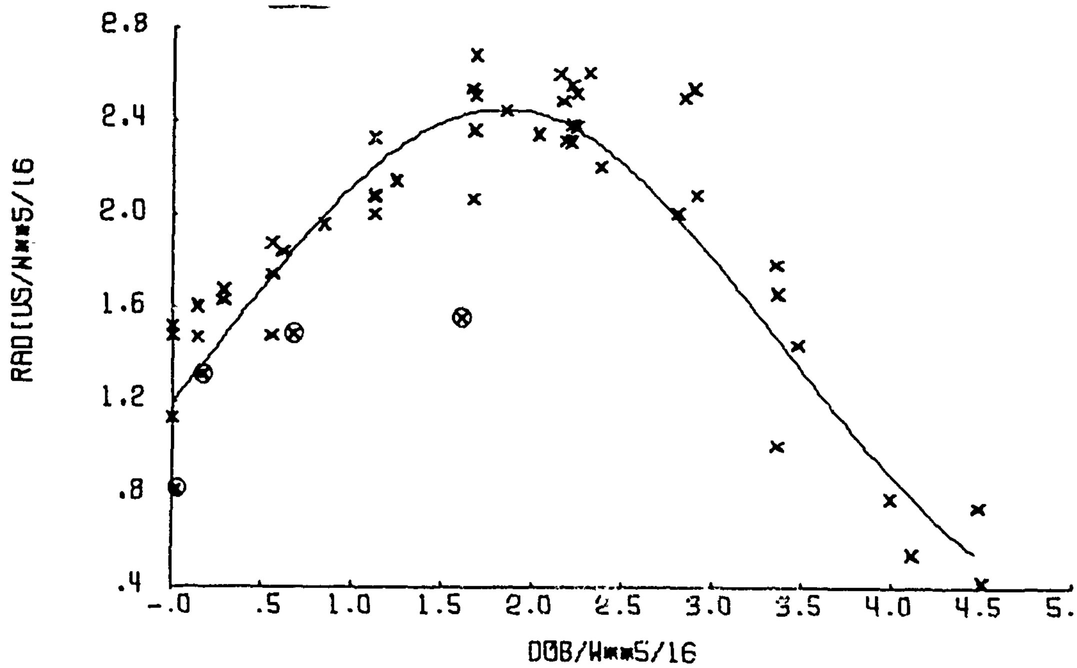


FIG. 8. CRATER RADIUS AS A FUNCTION OF CHARGE DEPTH FOR DESERT ALLUVIUM

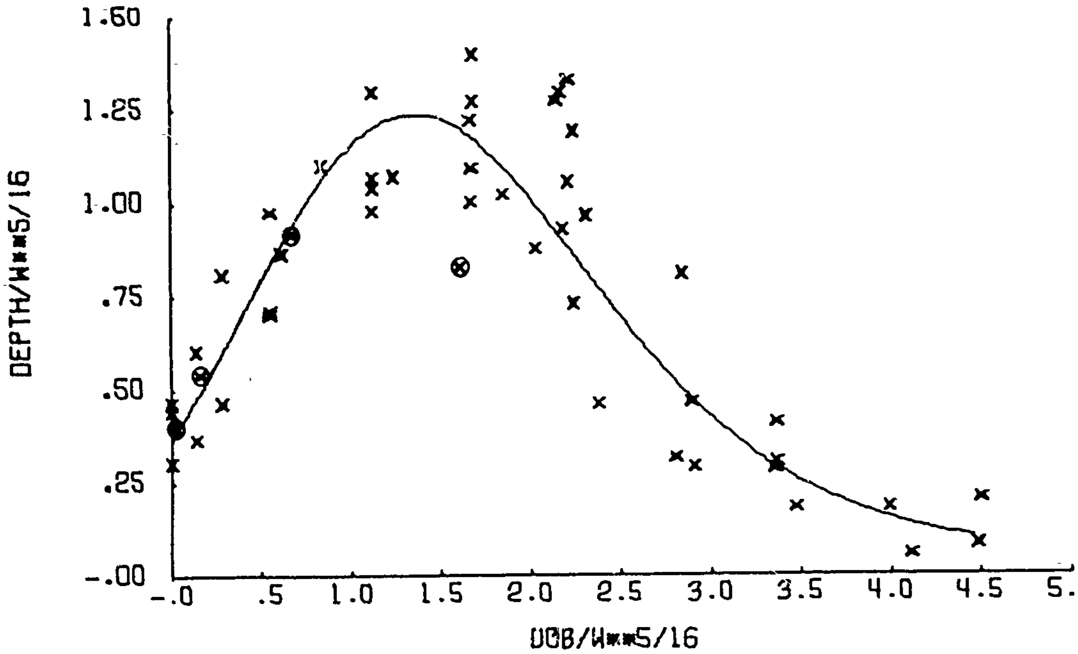


FIG. 9. CRATER DEPTH AS A FUNCTION OF CHARGE DEPTH FOR DESERT ALLUVIUM

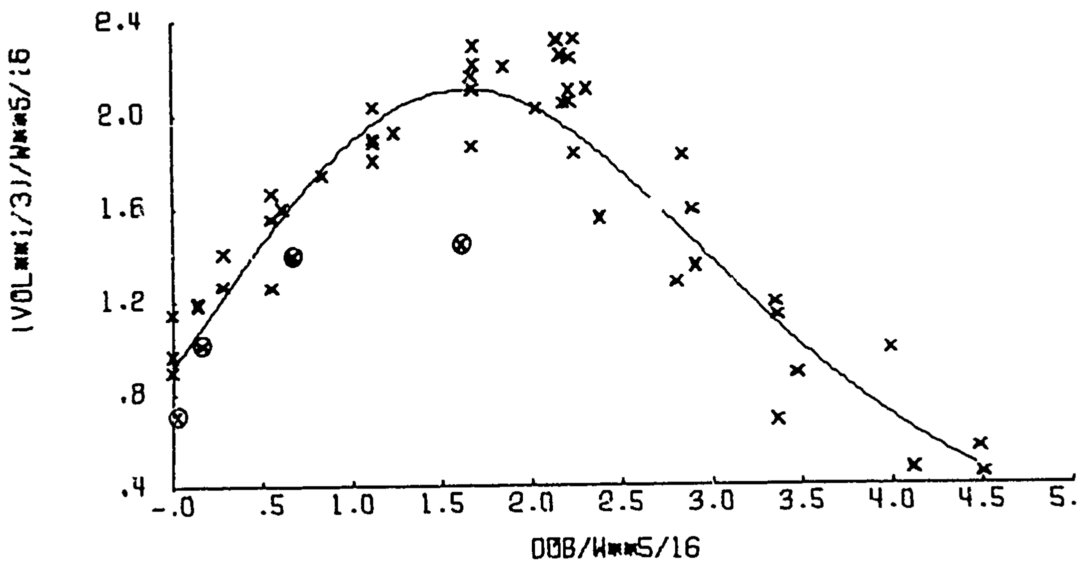


FIG. 10. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH FOR DESERT ALLUVIUM

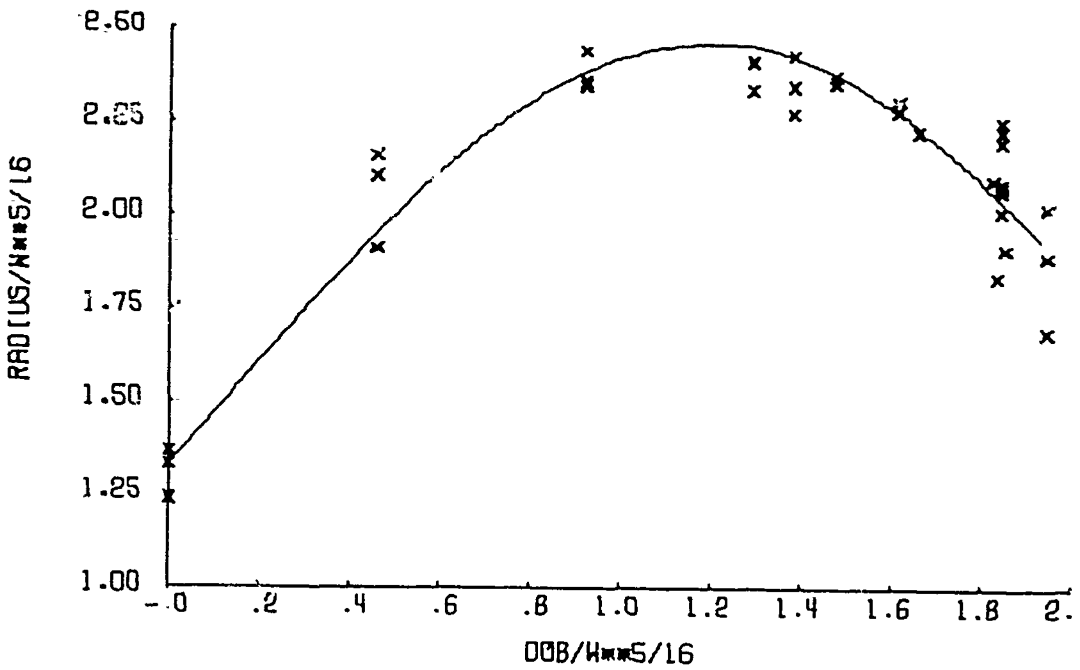


FIG. 11. CRATER RADIUS AS A FUNCTION OF CHARGE DEPTH FOR SAND

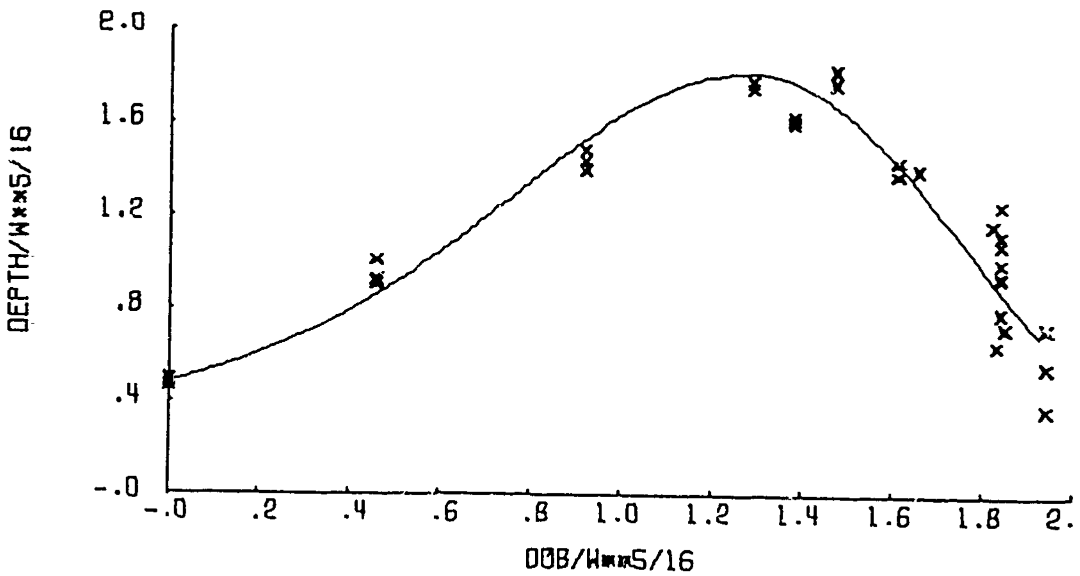


FIG. 12. CRATER DEPTH AS A FUNCTION OF CHARGE DEPTH FOR SAND

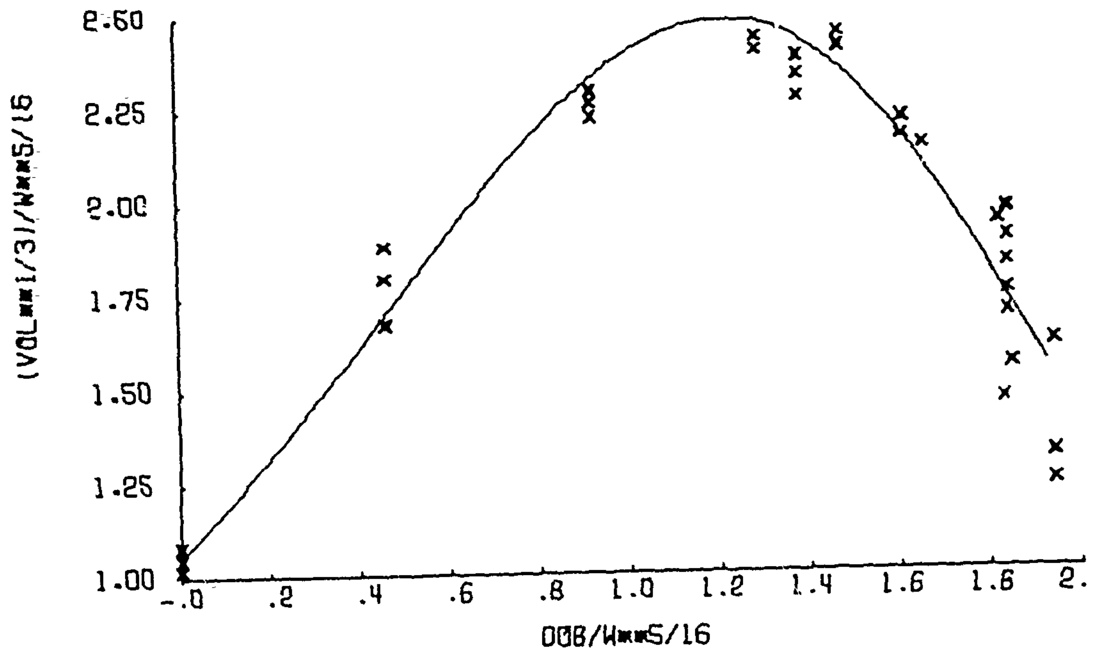


FIG. 13. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH FOR SAND

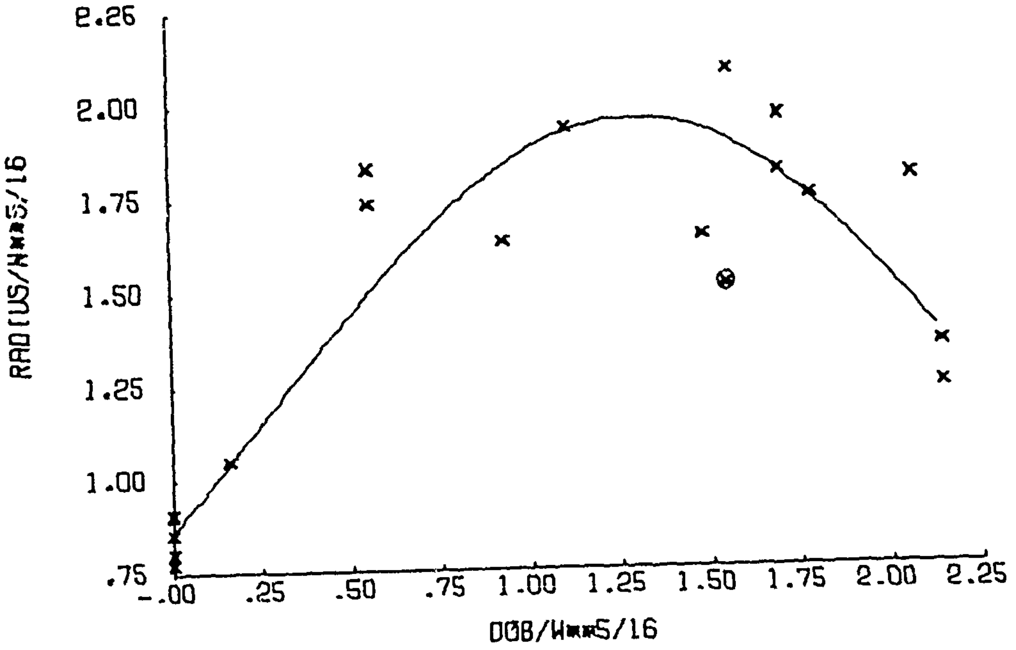


FIG. 14. CRATER RADIUS AS A FUNCTION OF CHARGE DEPTH FOR BASALT

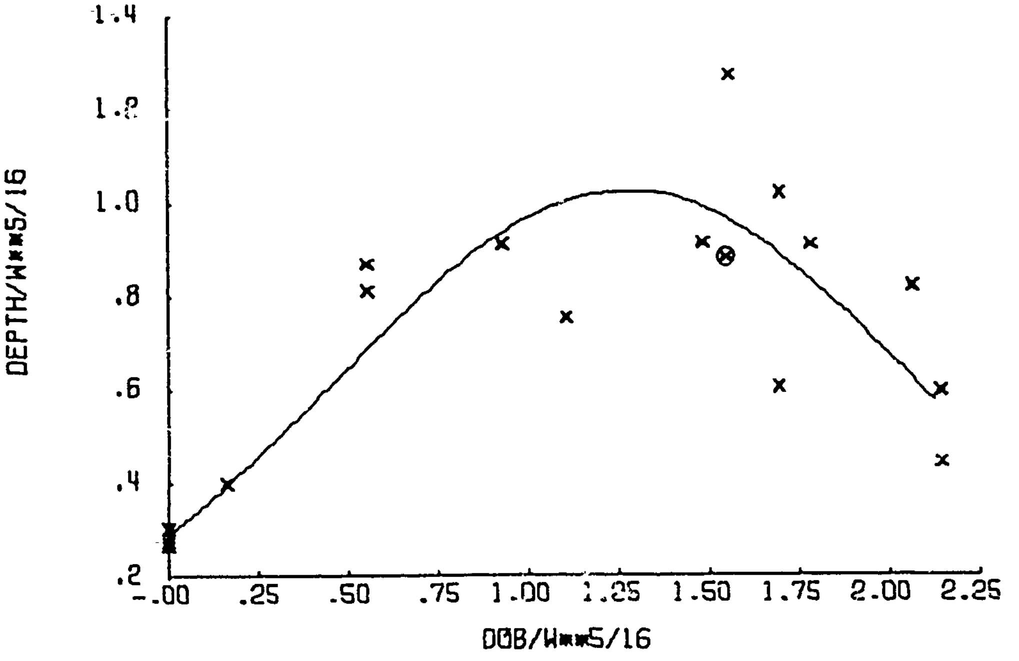


FIG. 15. CRATER DEPTH AS A FUNCTION OF CHARGE DEPTH FOR BASALT

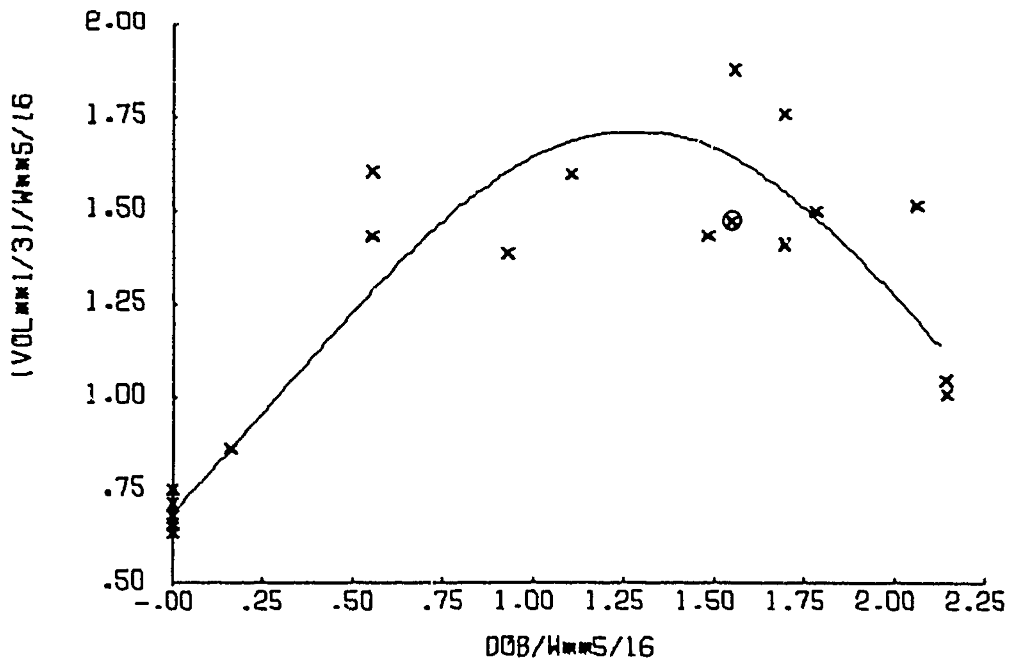


FIG. 16. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH FOR BASALT

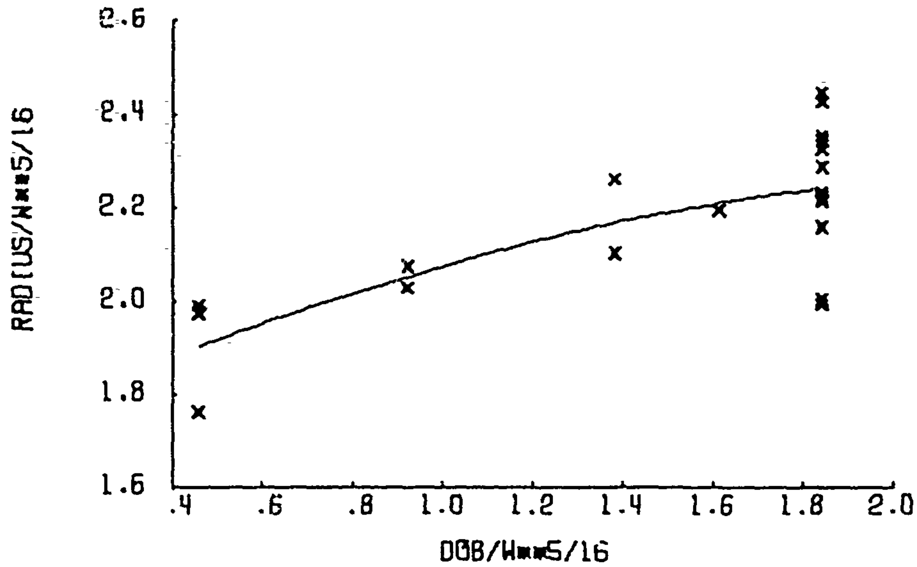


FIG. 17. CRATER RADIUS AS A FUNCTION OF CHARGE DEPTH FOR ALLUVIUM (ZULU SERIES)

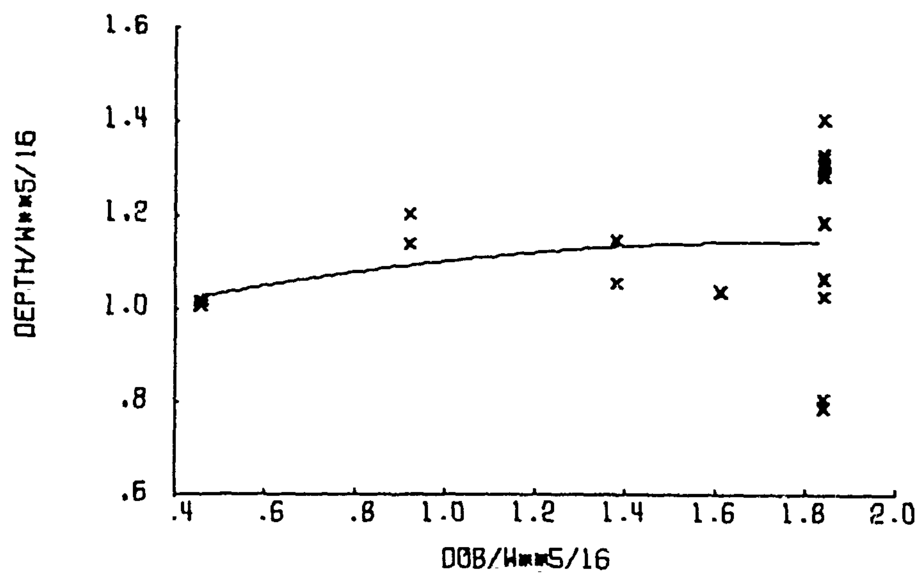


FIG. 18. CRATER DEPTH AS A FUNCTION OF CHARGE DEPTH FOR ALLUVIUM (ZULU SERIES)

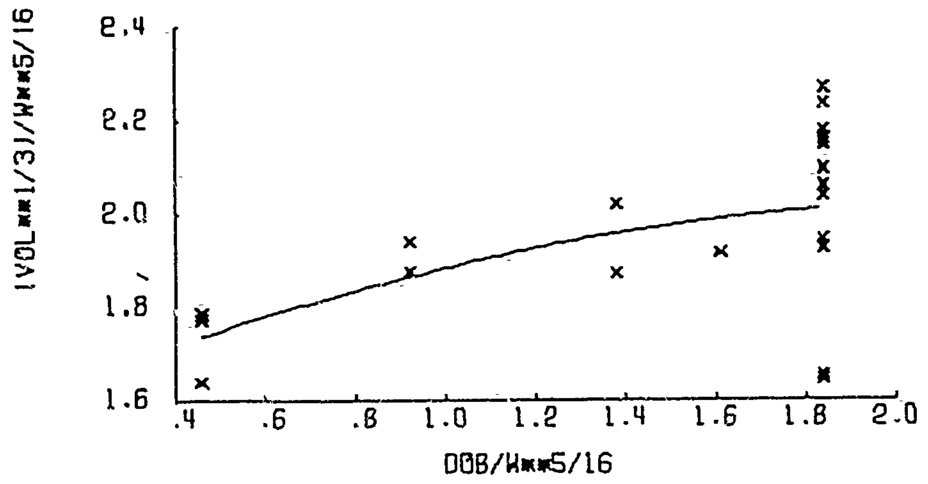


FIG. 19. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH FOR ALLUVIUM (ZULU SERIES)

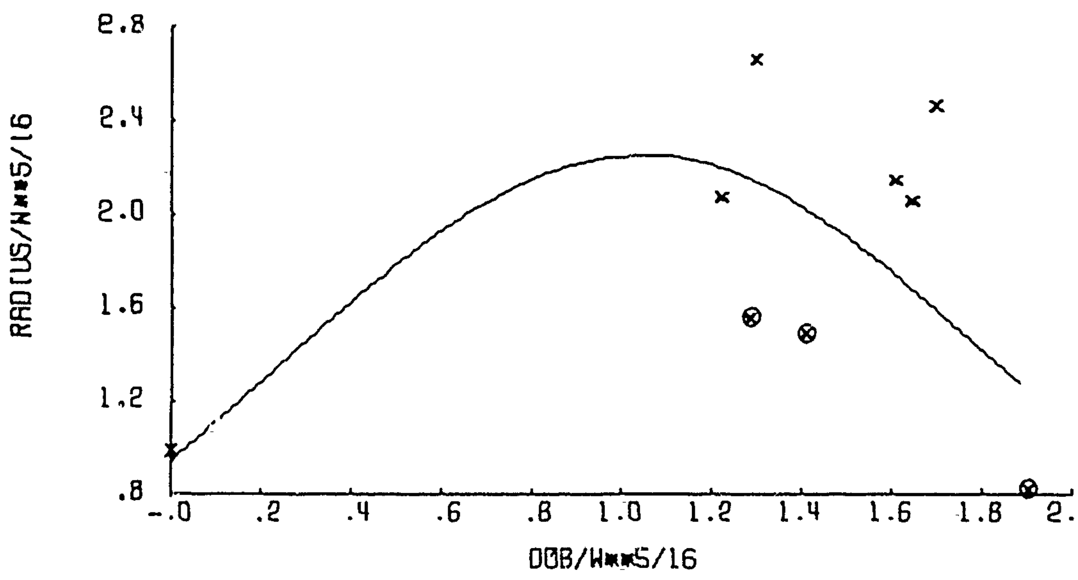


FIG. 20. CRATER RADIUS AS A FUNCTION OF CHARGE DEPTH FOR VARIOUS ROCK

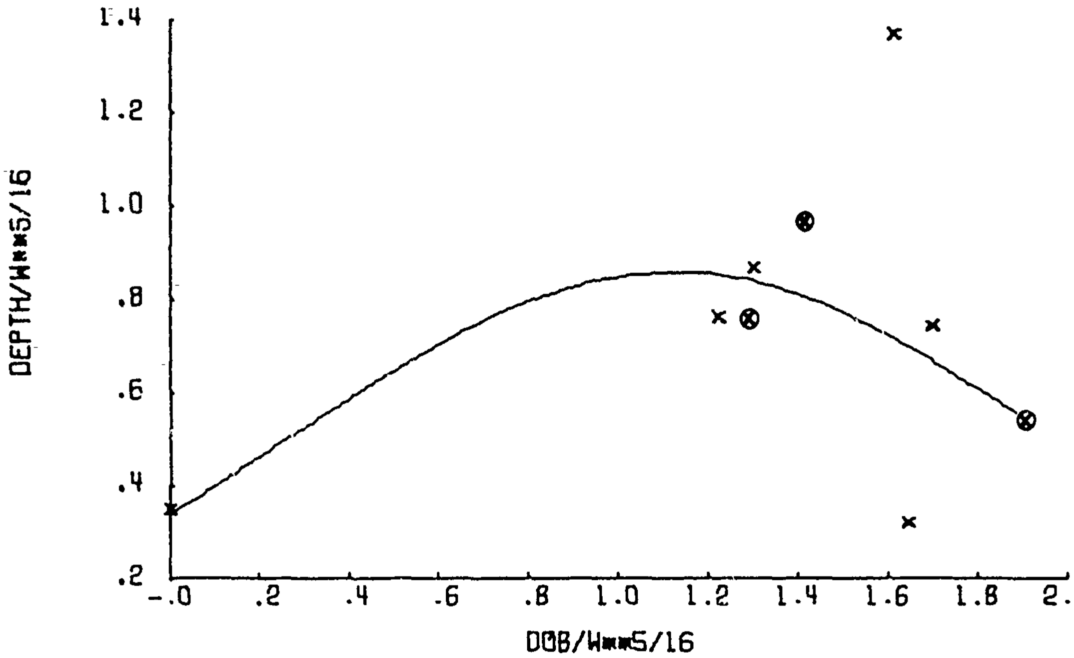


FIG. 21. CRATER DEPTH AS A FUNCTION OF CHARGE DEPTH FOR VARIOUS ROCK

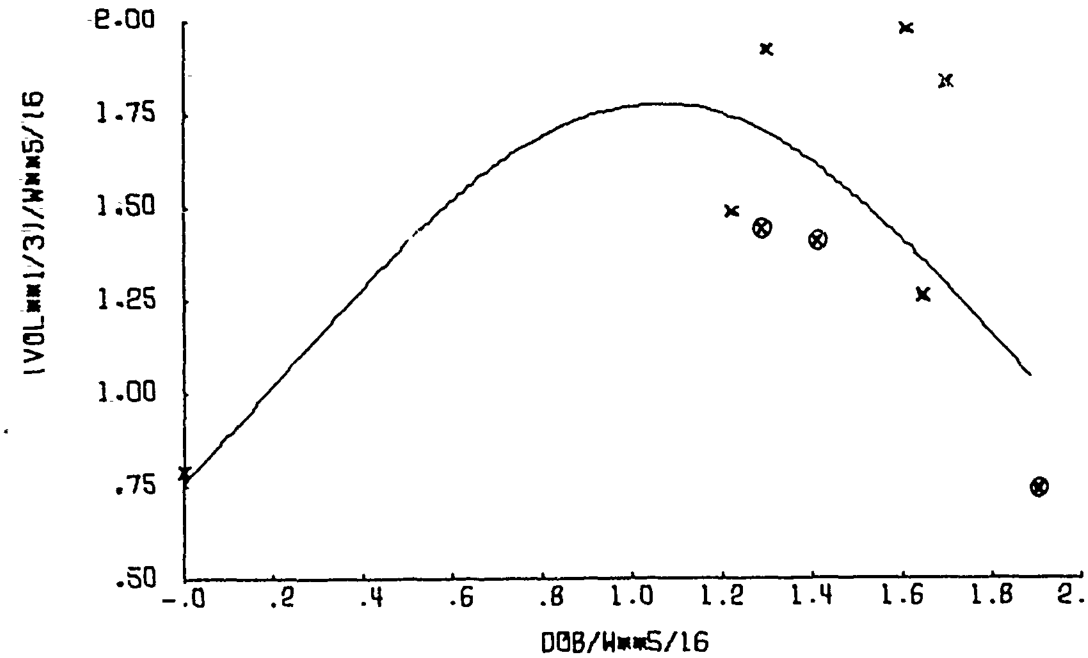


FIG. 22. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH FOR VARIOUS ROCK

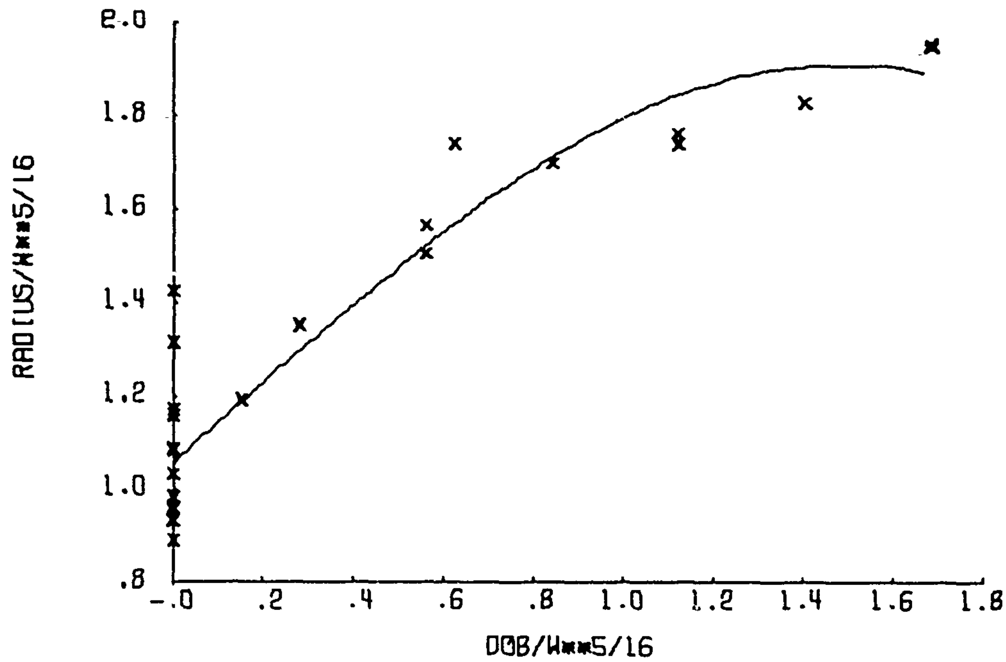


FIG. 23. CRATER RADIUS AS A FUNCTION OF CHARGE DEPTH FOR PLAYA (AIR VENT SERIES)

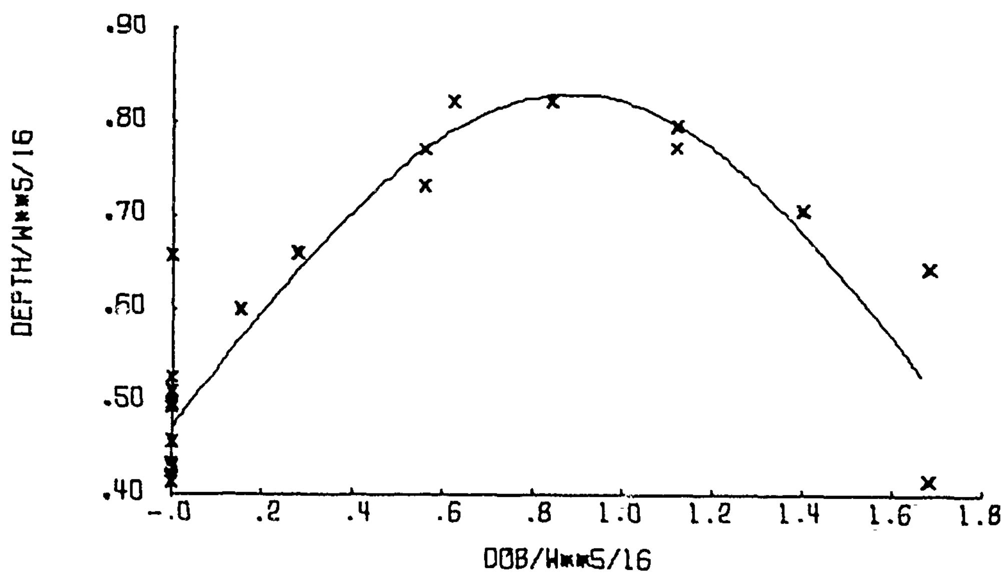


FIG. 24. CRATER DEPTH AS A FUNCTION OF CHARGE DEPTH FOR PLAYA (AIR VENT SERIES)

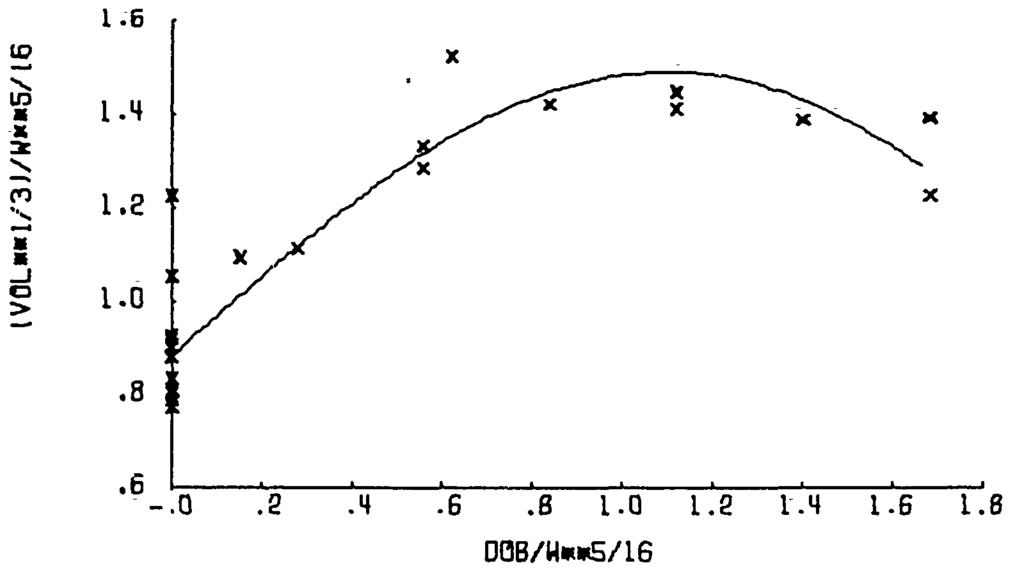


FIG. 25. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH FOR PLAYA (AIR VENT SERIES)

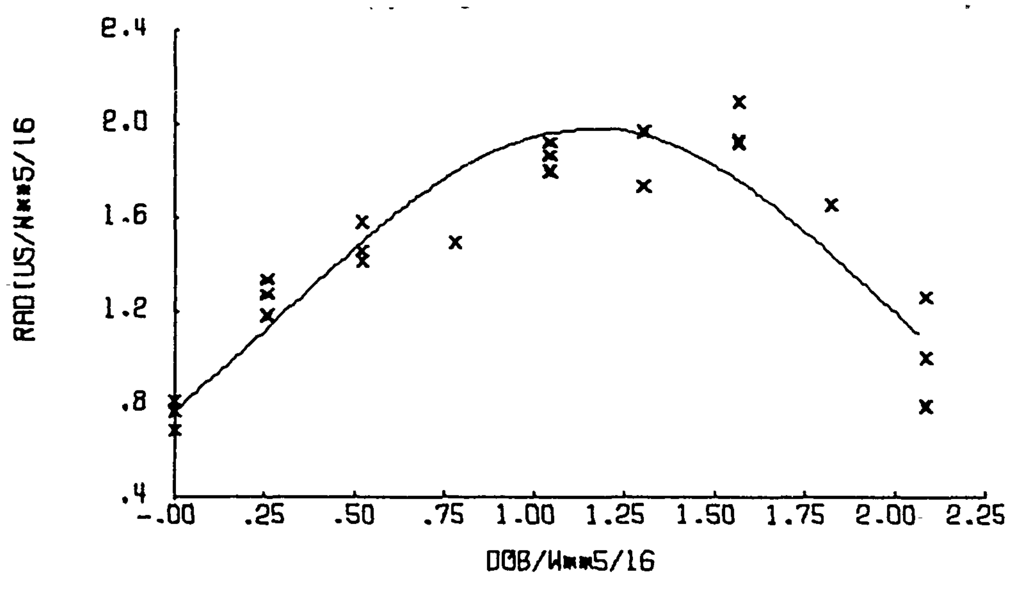


FIG. 26. CRATER RADIUS AS A FUNCTION OF CHARGE DEPTH FOR PLAYA (TOBOGGAN SERIES)

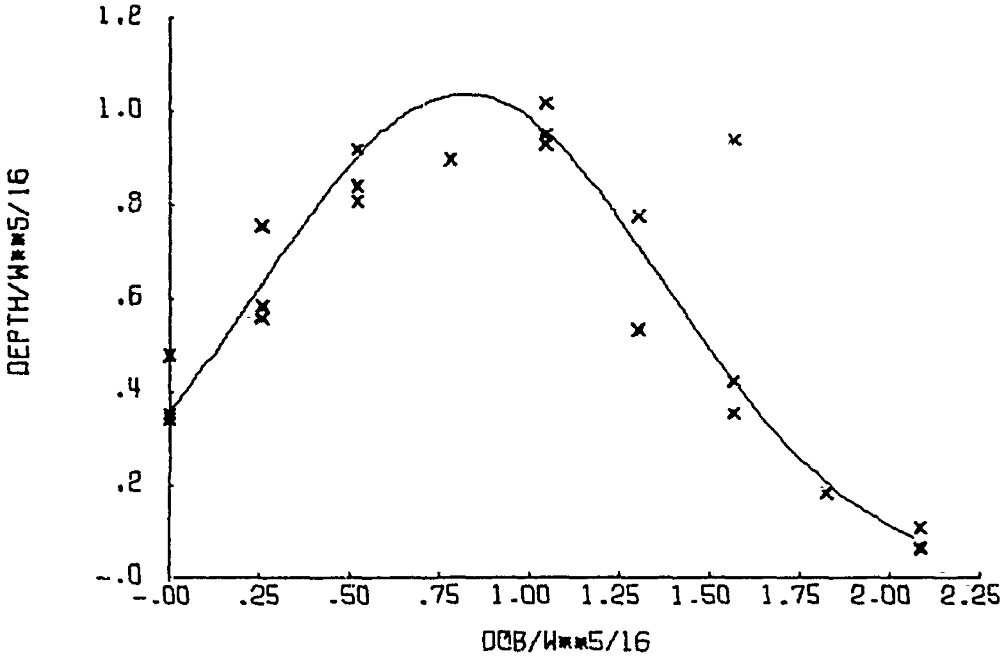


FIG. 27. CRATER DEPTH AS A FUNCTION OF CHARGE DEPTH FOR PLAYA (TOBOGGAN SERIES)

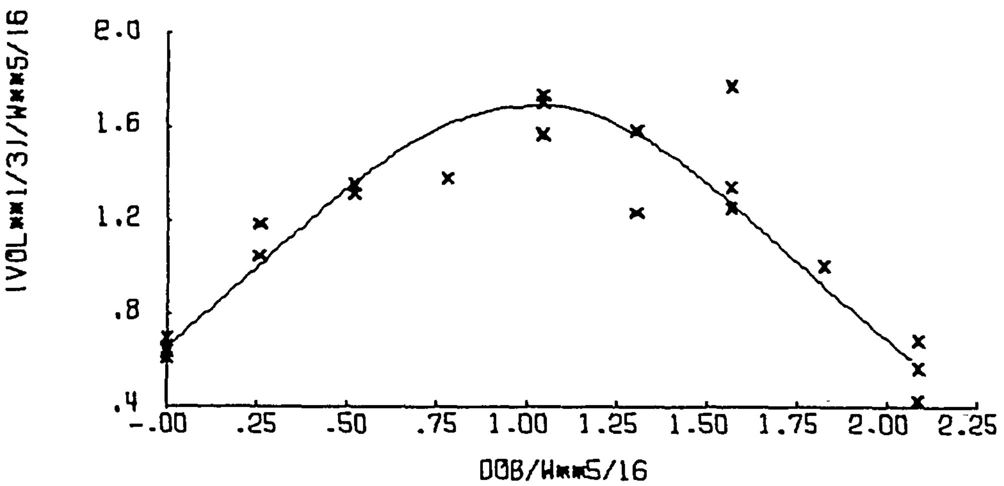


FIG. 28. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH FOR PLAYA (TOBOGGAN SERIES)

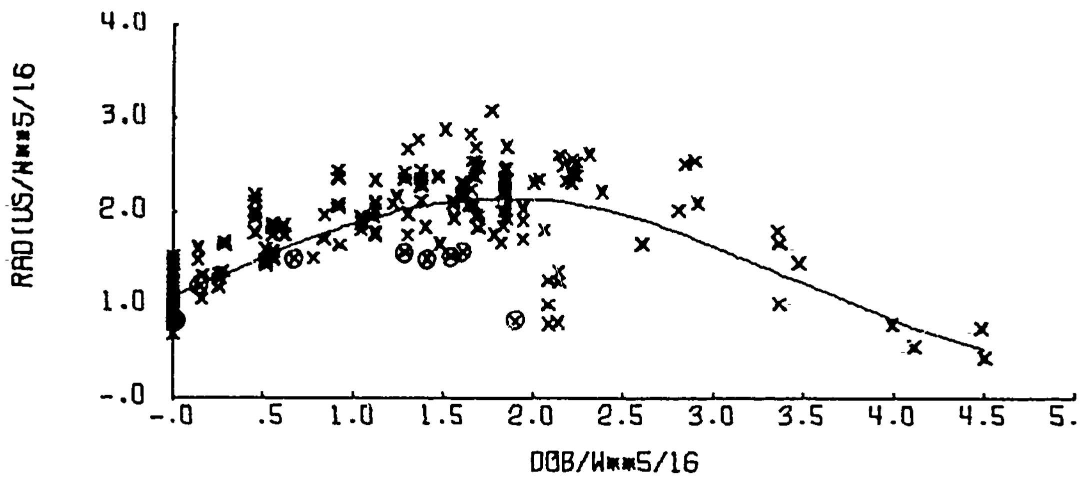


FIG. 29. CRATER RADIUS AS A FUNCTION OF CHARGE DEPTH FOR ALL THE DATA

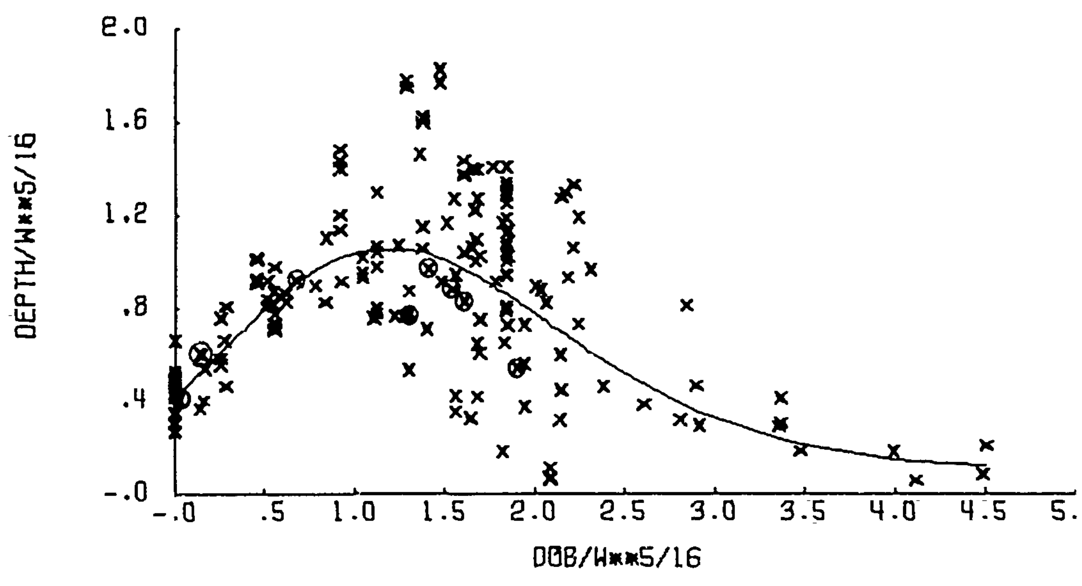


FIG. 30. CRATER DEPTH AS A FUNCTION OF CHARGE DEPTH FOR ALL THE DATA

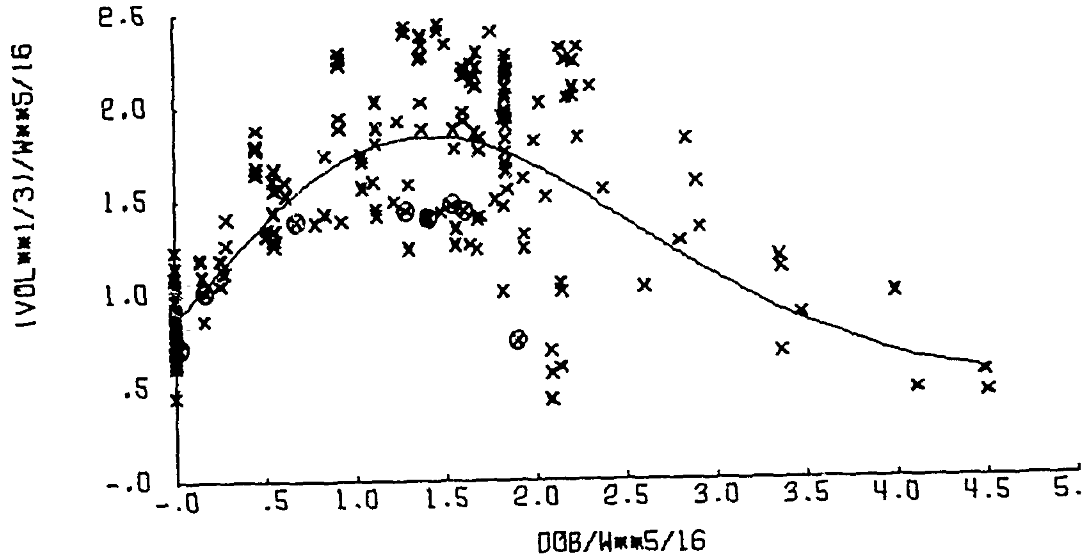


FIG. 31. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH FOR ALL THE DATA

APPENDIX IV

GENERAL EQUATION COEFFICIENTS

TABLE 4. GENERAL EQUATION COEFFICIENTS FOR RADIUS

Using $\gamma^{5/16}$, S and G_s		Using $\gamma^{5/16}$, S, G_s and E_v	
C(1)=	-31.8910003863	C(1)=	4.7431667917
C(2)=	53.7596378609	C(2)=	-312.2659209015
C(3)=	-8.9711680343	C(3)=	85.1020403634
C(4)=	.5549490163	C(4)=	130.7525251740
C(5)=	-30.5239196038	C(5)=	2.2953850824
C(6)=	-3.3733199735	C(6)=	-.0000081432
C(7)=	-.9415056768	C(7)=	-52.3758442797
C(8)=	14.0810150798	C(8)=	-12.4911945922
C(9)=	5.0934471228	C(9)=	122.3636313152
C(10)=	-1.9052946210	C(10)=	-27.8147254654
C(11)=	-61.0822676775	C(11)=	-141.9455105232
C(12)=	10.5127003945	C(12)=	823.0631524578
C(13)=	-2.7082997779	C(13)=	-196.6141937964
C(14)=	41.4257955425	C(14)=	-251.5265120348
C(15)=	44.6352964490	C(15)=	-153.2196787518
C(16)=	4.3584334973	C(16)=	.0000127300
C(17)=	1.7054916517	C(17)=	96.2318031404
C(18)=	-9.6728410805	C(18)=	126.6088317324
C(19)=	-42.7140631702	C(19)=	-199.3081650438
C(20)=	3.8425311344	C(20)=	18.4750255695
C(21)=	71.0614236931	C(21)=	112.7398253173
C(22)=	-.8820397422	C(22)=	-551.6962384152
C(23)=	1.7405271634	C(23)=	124.3090113793
C(24)=	-53.1325358655	C(24)=	156.6485857970
C(25)=	-30.3299093539	C(25)=	184.2976000120
C(26)=	-1.4850841324	C(26)=	-.0000075941
C(27)=	4.1108960189	C(27)=	-48.5622042860
C(28)=	5.4834047720	C(28)=	-135.4375636625
C(29)=	26.7268983051	C(29)=	65.7358828227
C(30)=	-2.6092817849	C(30)=	13.9867726703
		C(31)=	-13.4793572557
R_m^2 = 95.9		C(32)=	112.2478478970
63% within ± 10%		C(33)=	-24.0214629682
88% within ± 20%		C(34)=	-38.9836998015
		C(35)=	-59.5632559447
		C(36)=	.0000004885
		C(37)=	7.3256515643
		C(38)=	39.1585126325
		C(39)=	5.2268297684
		C(40)=	-8.6972701637
		R_m^2 = 97.7	
		72% within ± 10%	
		91% within = 20%	

TABLE 4. GENERAL EQUATION COEFFICIENTS FOR RADIUS (CONTINUED)

Using $\gamma^{5/16}$, S, tan ϕ and Ev		Using $\gamma^{5/16}$, S, $c^{1/3}$ and E_V	
C(1)=	18.8992452280	C(1)=	29.3980672485
C(2)=	-31.8938433251	C(2)=	17.2560192731
C(3)=	20.3800253443	C(3)=	10.0203963175
C(4)=	-8.3982809715	C(4)=	-4.4695237570
C(5)=	13.2362688240	C(5)=	-33.2041384178
C(6)=	-.0000027090	C(6)=	-.0000024075
C(7)=	.4473329001	C(7)=	-.0027363973
C(8)=	-17.5521678930	C(8)=	-6.6328662697
C(9)=	6.8566842352	C(9)=	3.6283822224
C(10)=	1.5946340224	C(10)=	-.1239487349
C(11)=	-199.0532997158	C(11)=	-122.3373482461
C(12)=	323.2985371981	C(12)=	-7.4095270897
C(13)=	-116.5369735224	C(13)=	-46.8808333927
C(14)=	64.5695519242	C(14)=	14.6150371805
C(15)=	-128.5006629243	C(15)=	89.2867812633
C(16)=	-.0000105683	C(16)=	-.0000056701
C(17)=	-4.0691506255	C(17)=	.0232794158
C(18)=	94.5027765293	C(18)=	38.5678057694
C(19)=	-51.7359125275	C(19)=	-12.2559501818
C(20)=	-1.0595754093	C(20)=	.0819726642
C(21)=	225.6633484300	C(21)=	95.1305302502
C(22)=	-361.8623322798	C(22)=	38.7459131358
C(23)=	125.7080514578	C(23)=	22.0664331670
C(24)=	-76.6928891978	C(24)=	-13.1284346475
C(25)=	140.4383152831	C(25)=	-96.2455129445
C(26)=	.0000176320	C(26)=	.0000127685
C(27)=	2.5802228123	C(27)=	-.0114900343
C(28)=	-96.9396721804	C(28)=	-13.6140033792
C(29)=	66.0886604123	C(29)=	10.8696441627
C(30)=	-6.9956496680	C(30)=	-.3975240262
C(31)=	-68.9475372938	C(31)=	-24.6729413515
C(32)=	109.5418270782	C(32)=	-13.6655896118
C(33)=	-37.8928184431	C(33)=	-.8950301282
C(34)=	24.9124062737	C(34)=	3.5235047360
C(35)=	-41.8140082327	C(35)=	27.6217414053
C(36)=	-.0000078407	C(36)=	-.0000066210
C(37)=	-.3086871023	C(37)=	-.0011715210
C(38)=	28.2818514475	C(38)=	-2.1689813568
C(39)=	-22.3678557147	C(39)=	-2.8343303860
C(40)=	3.8323586654	C(40)=	.2215007438
R_m^2 = 98.1		R_m^2 = 97.7	
76% within ± 10%		73% within ± 10%	
94% within ± 20%		95% within ± 20%	

TABLE 5. GENERAL EQUATION COEFFICIENTS FOR DEPTH

Using $\gamma^{5/16}$, S and G_s		Using $\gamma^{5/16}$, S, G_s and E_v	
C(1)=	53.3958631782	C(1)=	-43.6955704922
C(2)=	-127.9226404562	C(2)=	-263.0260424584
C(3)=	20.8301124395	C(3)=	76.0756460918
C(4)=	17.9316706900	C(4)=	143.4022465293
C(5)=	-48.4457154475	C(5)=	14.6854054001
C(6)=	-.5180822422	C(6)=	-.0000018621
C(7)=	-24.1731506505	C(7)=	-47.1730917167
C(8)=	15.8709481683	C(8)=	-15.6964256288
C(9)=	91.6107413501	C(9)=	90.9027550405
C(10)=	-15.2484978757	C(10)=	-22.2985600530
C(11)=	-449.1867152981	C(11)=	87.0048968184
C(12)=	368.5656181405	C(12)=	660.3121352892
C(13)=	-44.6720935833	C(13)=	-126.3905248215
C(14)=	166.2582151665	C(14)=	-354.1566836962
C(15)=	66.2414675220	C(15)=	-82.2950451510
C(16)=	-3.7716040549	C(16)=	.0000200377
C(17)=	17.9221947624	C(17)=	112.9332700877
C(18)=	11.5629558875	C(18)=	90.8534757507
C(19)=	-205.3794622239	C(19)=	-193.3862745518
C(20)=	13.0681609205	C(20)=	8.2417379757
C(21)=	254.9573454245	C(21)=	-598.9320341567
C(22)=	-120.7791721681	C(22)=	-523.9584928841
C(23)=	14.2414607555	C(23)=	41.3421692588
C(24)=	-134.8771751525	C(24)=	689.3555775039
C(25)=	-51.6017664322	C(25)=	107.4665743070
C(26)=	1.9569970889	C(26)=	-.0000353688
C(27)=	2.9310692111	C(27)=	-160.9998103999
C(28)=	-.1726515931	C(28)=	-93.9073485683
C(29)=	94.4689354767	C(29)=	118.7384287103
C(30)=	-6.0438470627	C(30)=	25.6274231778
R_m^2 = 93.6		C(31)=	342.2023179307
39% within ± 10%		C(32)=	175.6525289593
65% within ± 20%		C(33)=	.3384907975
		C(34)=	-340.1575068641
		C(35)=	-53.7051347245
		C(36)=	.0000144488
		C(37)=	71.4063952381
		C(38)=	33.5127395672
		C(39)=	-23.9273648252
		C(40)=	-15.1138557381
		R_m^2 = 96.0	
		47% within ± 10%	
		72% within ± 20%	

TABLE 5. GENERAL EQUATION COEFFICIENTS FOR DEPTH (CONTINUED)

Using $\gamma^{5/16}$, S, tan ϕ and E_v		Using $\gamma^{5/16}$, S, $c^{1/3}$ and E_v	
C(1)=	17.1253607120	C(1)=	21.7086303701
C(2)=	-37.3542155845	C(2)=	-42.8323530877
C(3)=	12.5105364460	C(3)=	14.6236850658
C(4)=	8.5029333445	C(4)=	.1510212049
C(5)=	14.7403694968	C(5)=	22.8611299509
C(6)=	.0000029697	C(6)=	.0000028219
C(7)=	-7.2058081245	C(7)=	.0096628854
C(8)=	-8.4253426900	C(8)=	-14.1319628653
C(9)=	3.3999072147	C(9)=	-.4996236569
C(10)=	-1.8629595715	C(10)=	.2047476495
C(11)=	-193.3918309651	C(11)=	-85.5758975799
C(12)=	330.9456858185	C(12)=	112.7124014239
C(13)=	-97.2329269833	C(13)=	-25.8772673551
C(14)=	33.0550538845	C(14)=	2.6748938298
C(15)=	-134.3558827033	C(15)=	-45.0963840333
C(16)=	-.0000253473	C(16)=	-.0000128280
C(17)=	4.4905080385	C(17)=	-.0277178934
C(18)=	72.4656077635	C(18)=	32.4942151045
C(19)=	-37.2785637467	C(19)=	-.9376620835
C(20)=	7.6485959924	C(20)=	-.7761191183
C(21)=	219.4717738692	C(21)=	90.0293948233
C(22)=	-361.0416787948	C(22)=	-86.5807061318
C(23)=	113.5789573079	C(23)=	-16.6599345535
C(24)=	-63.5462262740	C(24)=	-4.1166825850
C(25)=	144.1389355682	C(25)=	27.0640857132
C(26)=	.0000298469	C(26)=	.0000219664
C(27)=	2.6975157247	C(27)=	.0528352719
C(28)=	-83.6172087730	C(28)=	6.2005227228
C(29)=	54.6675138674	C(29)=	1.3423129962
C(30)=	-12.3071777708	C(30)=	.4649869039
C(31)=	-72.7217500189	C(31)=	-31.6097537754
C(32)=	116.2322451501	C(32)=	32.5439752740
C(33)=	-37.4935916521	C(33)=	11.4732120724
C(34)=	25.5528645197	C(34)=	1.1107085605
C(35)=	-45.3802628657	C(35)=	-12.4902317358
C(36)=	-.0000108194	C(36)=	-.0000104873
C(37)=	-1.3321194171	C(37)=	-.0264307464
C(38)=	27.3519570403	C(38)=	-8.2155628902
C(39)=	-21.3464789174	C(39)=	-.0050793512
C(40)=	4.9772599019	C(40)=	-.0721852584
R_m^2 = 94.5		R_m^2 = 97.8	
43% within ± 10%		45% within ± 10%	
66% within ± 20%		72% within ± 20%	

TABLE 6. GENERAL EQUATION COEFFICIENTS FOR VOLUME

Using $\gamma^{5/16}$, S and G_s		Using $\gamma^{5/16}$, S, G_s and E_v	
C(1)=	-2.1752357208	C(1)=	-11.8207236195
C(2)=	13.1141215646	C(2)=	-347.0492941075
C(3)=	.5997600122	C(3)=	97.9246661795
C(4)=	-3.6647026294	C(4)=	156.8518890100
C(5)=	-30.4405669790	C(5)=	10.5575210571
C(6)=	-3.4757992071	C(6)=	-.0000070368
C(7)=	-3.8080378705	C(7)=	-58.4668518002
C(8)=	14.9439527393	C(8)=	-16.1887586229
C(9)=	20.8239905858	C(9)=	128.5893232243
C(10)=	-5.9957649451	C(10)=	-30.9888871631
C(11)=	-215.7667550905	C(11)=	-59.3569012349
C(12)=	93.1623369378	C(12)=	875.9625480868
C(13)=	-16.5008692970	C(13)=	-209.5974746947
C(14)=	118.9135549083	C(14)=	-334.6553293740
C(15)=	33.8867065685	C(15)=	-147.6046367155
C(16)=	2.7663678702	C(16)=	.0000132385
C(17)=	-6.3022129785	C(17)=	117.2272444498
C(18)=	2.7930938894	C(18)=	131.0815866705
C(19)=	-67.2103550710	C(19)=	-224.9307823733
C(20)=	4.0009580189	C(20)=	21.5972214015
C(21)=	146.3688958239	C(21)=	-134.8691756255
C(22)=	-25.5385254205	C(22)=	-617.5477326839
C(23)=	6.3873929627	C(23)=	122.2498533469
C(24)=	-98.0675342208	C(24)=	372.8148507687
C(25)=	-30.2435268423	C(25)=	163.4194029422
C(26)=	-.6234156121	C(26)=	-.0000111033
C(27)=	9.8235554535	C(27)=	-99.1900726417
C(28)=	1.2453679293	C(28)=	-133.4532348238
C(29)=	37.1186765414	C(29)=	109.7545480632
C(30)=	-2.7689859994	C(30)=	13.5108852373
R_m^2 = 94.7		C(31)=	109.1642310421
59% within ± 10%		C(32)=	152.1133991992
84% within ± 20%		C(33)=	-21.4879680004
		C(34)=	-150.2371189017
		C(35)=	-55.9322230211
		C(36)=	.0000026885
		C(37)=	32.7649358627
		C(38)=	39.6790168769
		C(39)=	-13.5594018538
		C(40)=	-9.8179260609
		R_m^2 = 97.2	
		65% within ± 10%	
		89% within ± 20%	

TABLE 6. GENERAL EQUATION COEFFICIENTS FOR VOLUME (CONTINUED)

Using $\gamma^{5/16}$, S, tan ϕ and E_v		Using $\gamma^{5/16}$, S, $c^{1/3}$, and E_v	
C(1)=	22.3706247625	C(1)=	20.4178474204
C(2)=	-38.9723779360	C(2)=	6.7210259113
C(3)=	18.9610934544	C(3)=	11.9976882110
C(4)=	-5.7817278439	C(4)=	-2.8361992670
C(5)=	15.6413196900	C(5)=	-17.5564771871
C(6)=	-.0000019613	C(6)=	-.0000012370
C(7)=	-1.4903246793	C(7)=	.0043463631
C(8)=	-15.6027125598	C(8)=	-9.5472334444
C(9)=	7.4617827708	C(9)=	2.1150419147
C(10)=	.2976374547	C(10)=	-.0237115989
C(11)=	-205.6266042500	C(11)=	-88.7714888573
C(12)=	332.7916277065	C(12)=	-1.0129467374
C(13)=	-107.5617213000	C(13)=	-40.4980003277
C(14)=	65.3451232213	C(14)=	10.4469006002
C(15)=	-131.0986024125	C(15)=	56.2397519728
C(16)=	-.0000133713	C(16)=	-.0000128355
C(17)=	-2.7122525642	C(17)=	-.0069710347
C(18)=	85.1580280890	C(18)=	36.2108467755
C(19)=	-54.5527834882	C(19)=	-8.0426022638
C(20)=	2.9801404833	C(20)=	-.1288631602
C(21)=	224.1213882024	C(21)=	70.9874042555
C(22)=	-355.1369302715	C(22)=	39.8818213383
C(23)=	115.5598816362	C(23)=	5.8251333617
C(24)=	-82.6517911088	C(24)=	-10.3385864958
C(25)=	136.3420036066	C(25)=	-73.6285916503
C(26)=	.0000208297	C(26)=	.0000259077
C(27)=	3.6172294428	C(27)=	.0240818543
C(28)=	-87.3706458740	C(28)=	-2.6011605498
C(29)=	69.9345875052	C(29)=	7.5554455247
C(30)=	-10.0936503158	C(30)=	-.2349178007
C(31)=	-68.0570038646	C(31)=	-20.2504191554
C(32)=	105.8756257875	C(32)=	-13.2365012983
C(33)=	-35.1328556613	C(33)=	4.7647670677
C(34)=	28.2071799715	C(34)=	2.9103610175
C(35)=	-39.6850247712	C(35)=	21.5041290063
C(36)=	-.0000087052	C(36)=	-.0000121125
C(37)=	-.9340846773	C(37)=	-.0138504245
C(38)=	25.7701411555	C(38)=	-5.1011694772
C(39)=	-24.3306349045	C(39)=	-1.9502307115
C(40)=	4.5780233701	C(40)=	.1689371705
R_m^2 = 96.9		R_m^2 = 97.8	
66% within ± 10%		65% within ± 10%	
92% within ± 20%		93% within ± 20%	

APPENDIX V

MATERIAL PROPERTY EFFECTS PLOTS

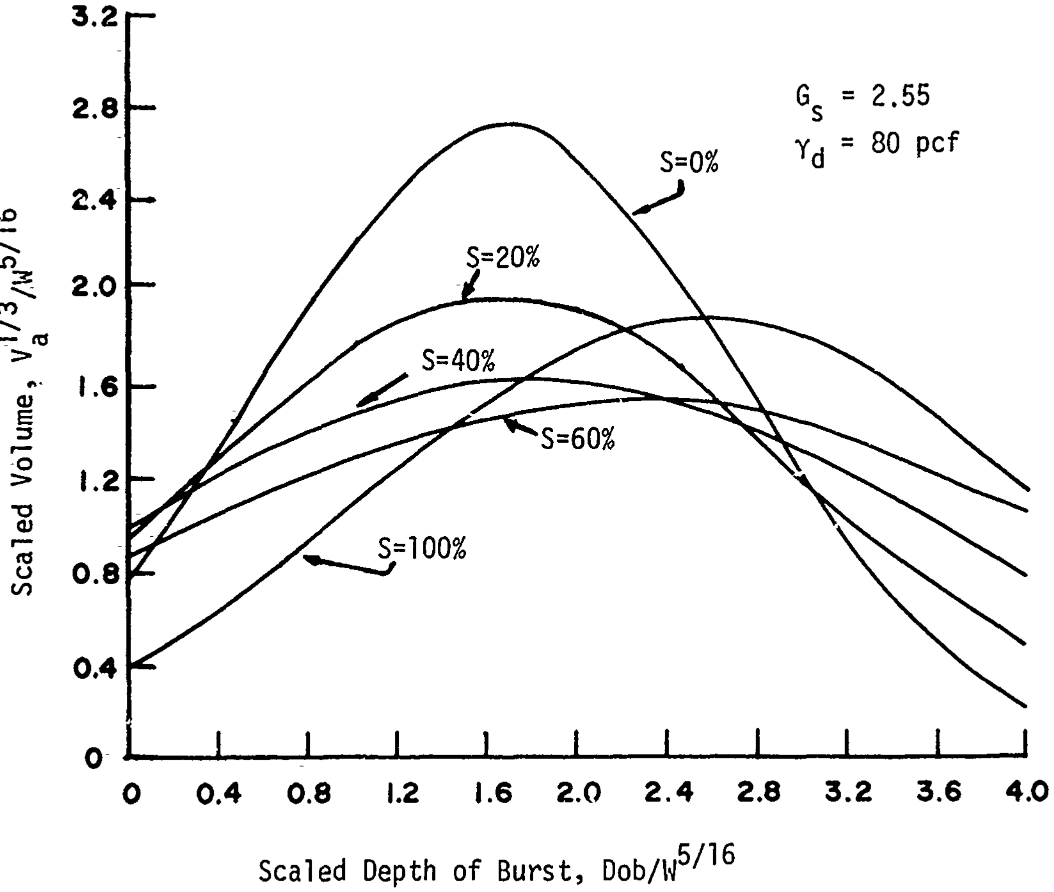


FIG. 32. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH AND PERCENT SATURATION, S, FOR SPECIFIC GRAVITY = 2.55 AND DRY UNIT WEIGHT = 80 POUNDS/CUBIC FOOT

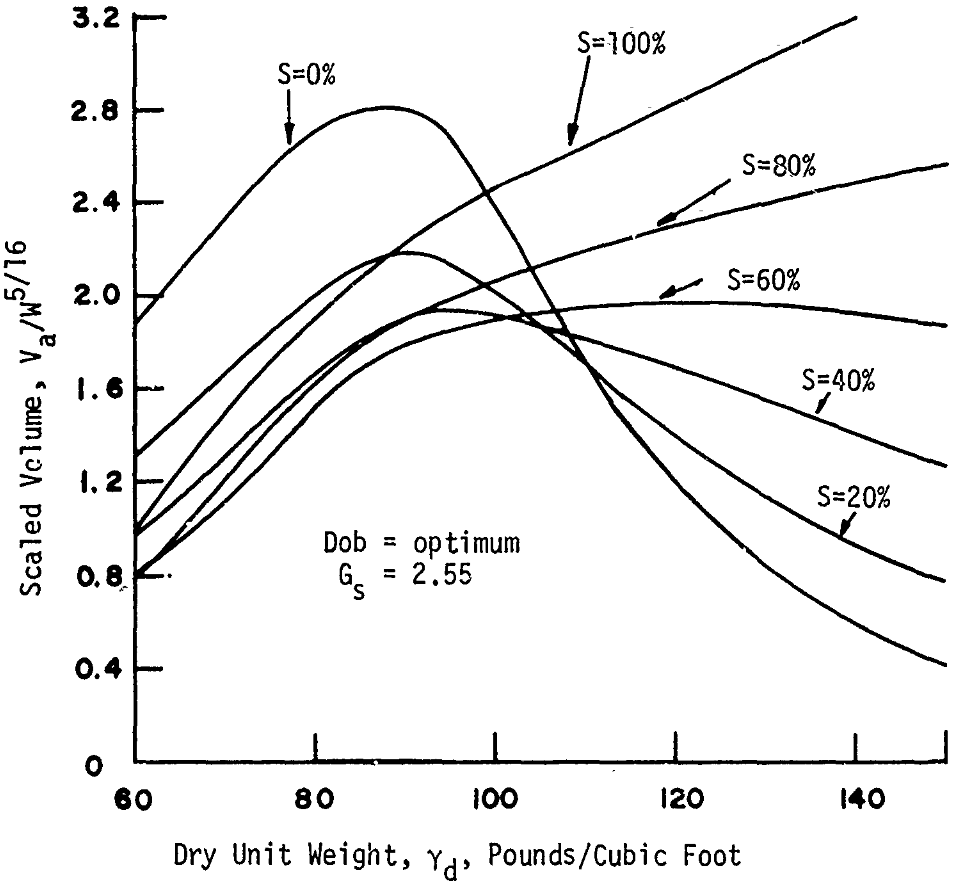


FIG. 33. CRATER VOLUME AS A FUNCTION OF DRY UNIT WEIGHT AND PERCENT SATURATION, S, FOR OPTIMUM CHARGE DEPTH AND SPECIFIC GRAVITY = 2.55

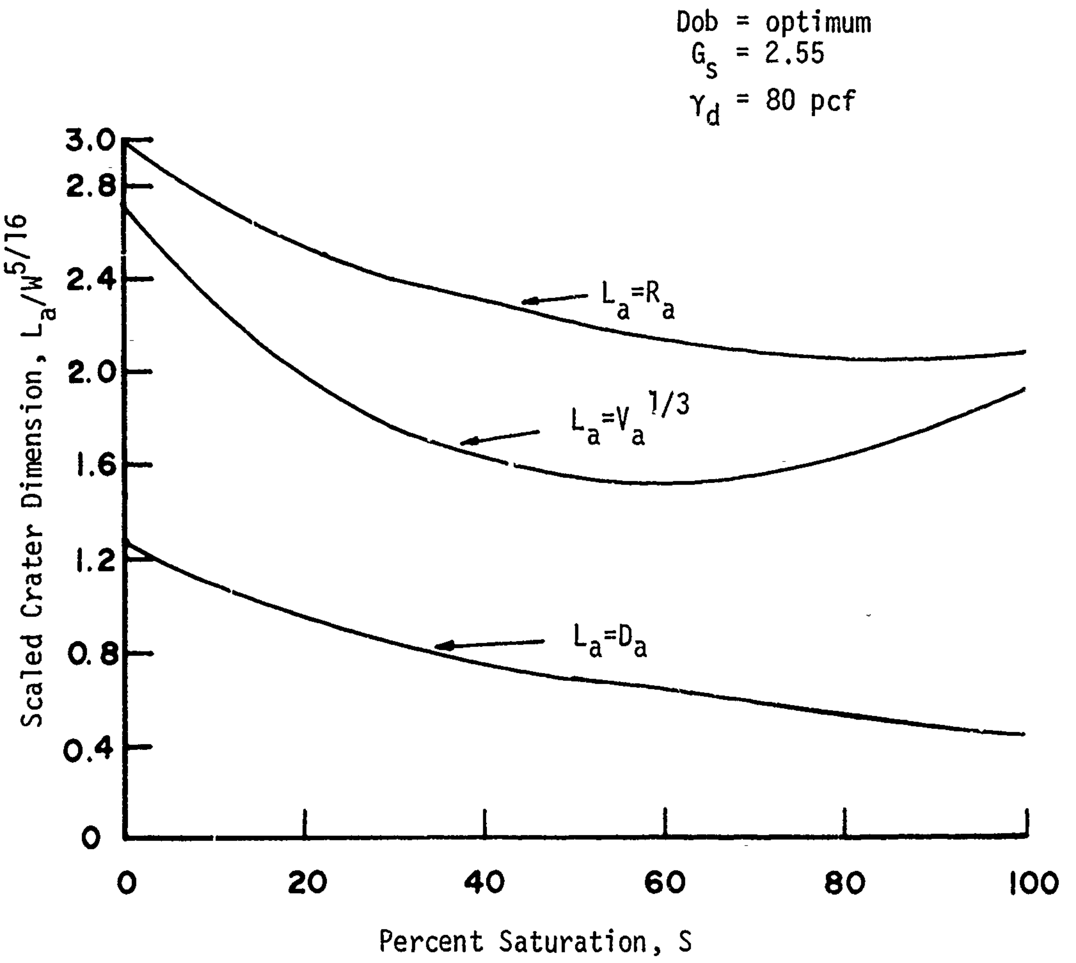


FIG. 34. CRATER RADIUS, DEPTH AND VOLUME AS A FUNCTION OF PERCENT SATURATION FOR OPTIMUM CHARGE DEPTH, SPECIFIC GRAVITY = 2.55 AND DRY UNIT WEIGHT = 80 POUNDS/CUBIC FOOT

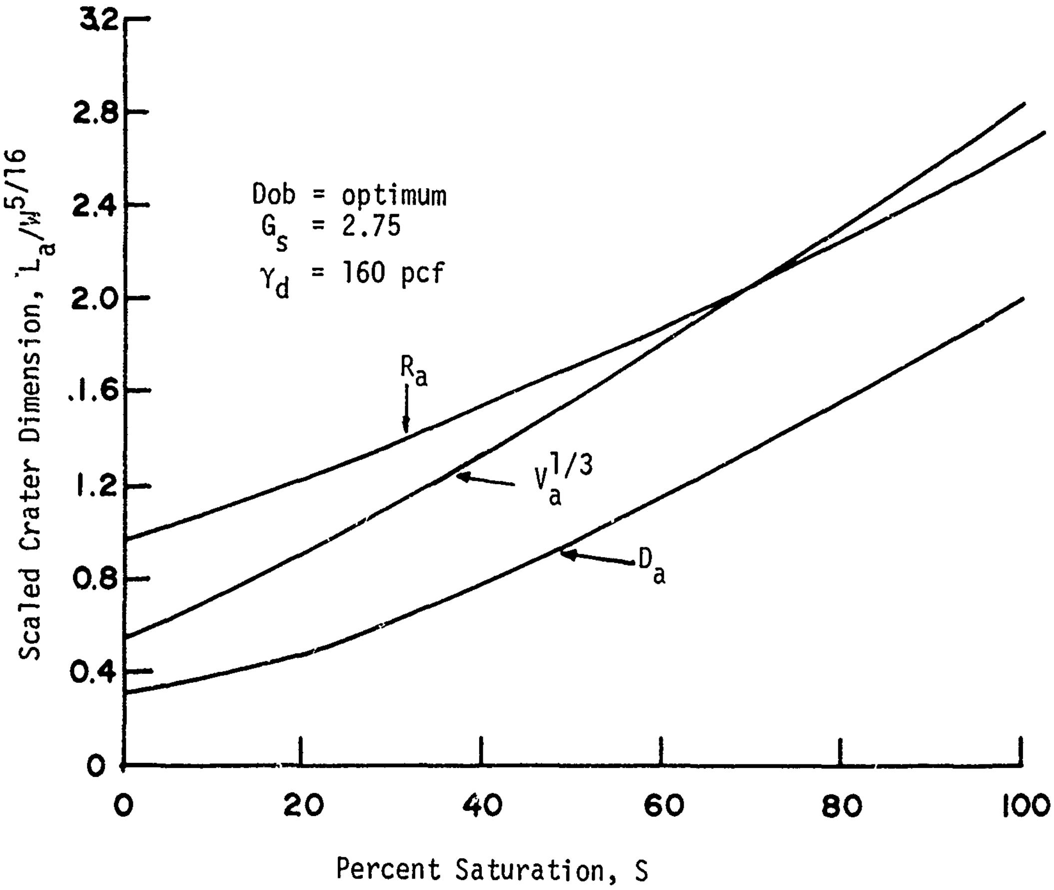


FIG. 35. CRATER RADIUS, DEPTH AND VOLUME AS A FUNCTION OF PERCENT SATURATION FOR OPTIMUM CHARGE DEPTH, SPECIFIC GRAVITY = 2.75 AND DRY UNIT WEIGHT = 160 POUNDS/CUBIC FOOT

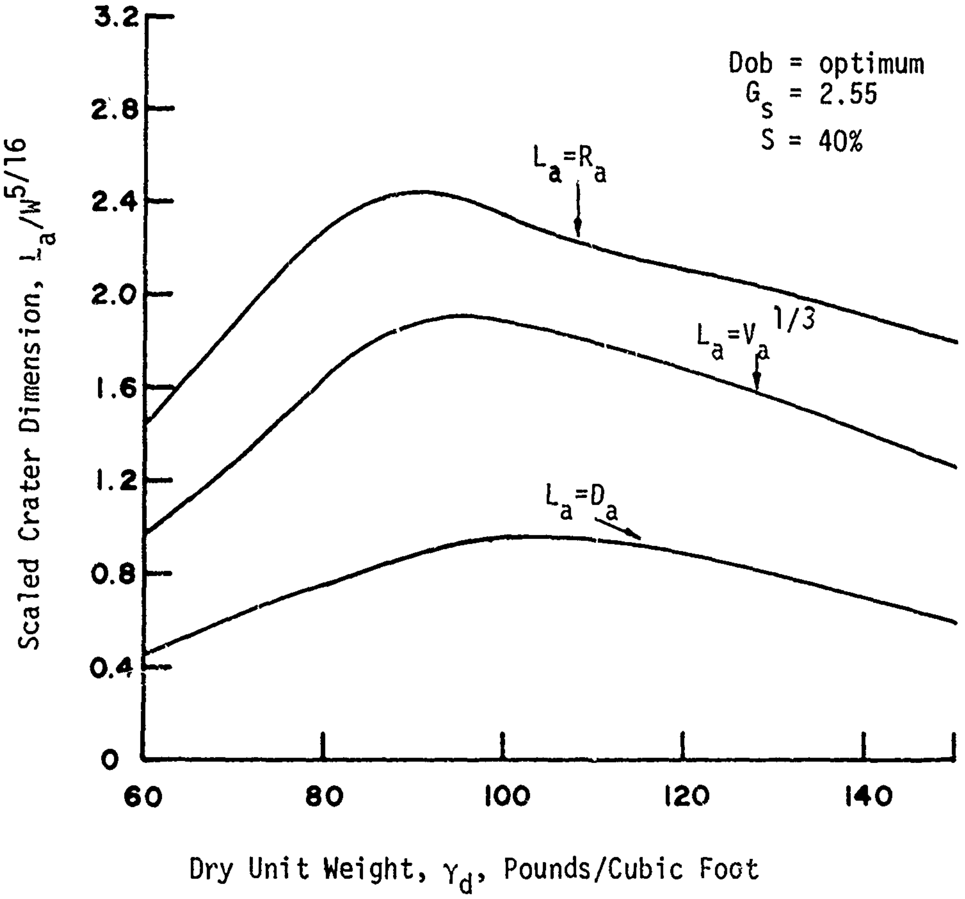


FIG. 36. CRATER RADIUS, DEPTH AND VOLUME AS A FUNCTION OF DRY UNIT WEIGHT FOR OPTIMUM CHARGE DEPTH, SPECIFIC GRAVITY = 2.55 AND PERCENT SATURATION = 40

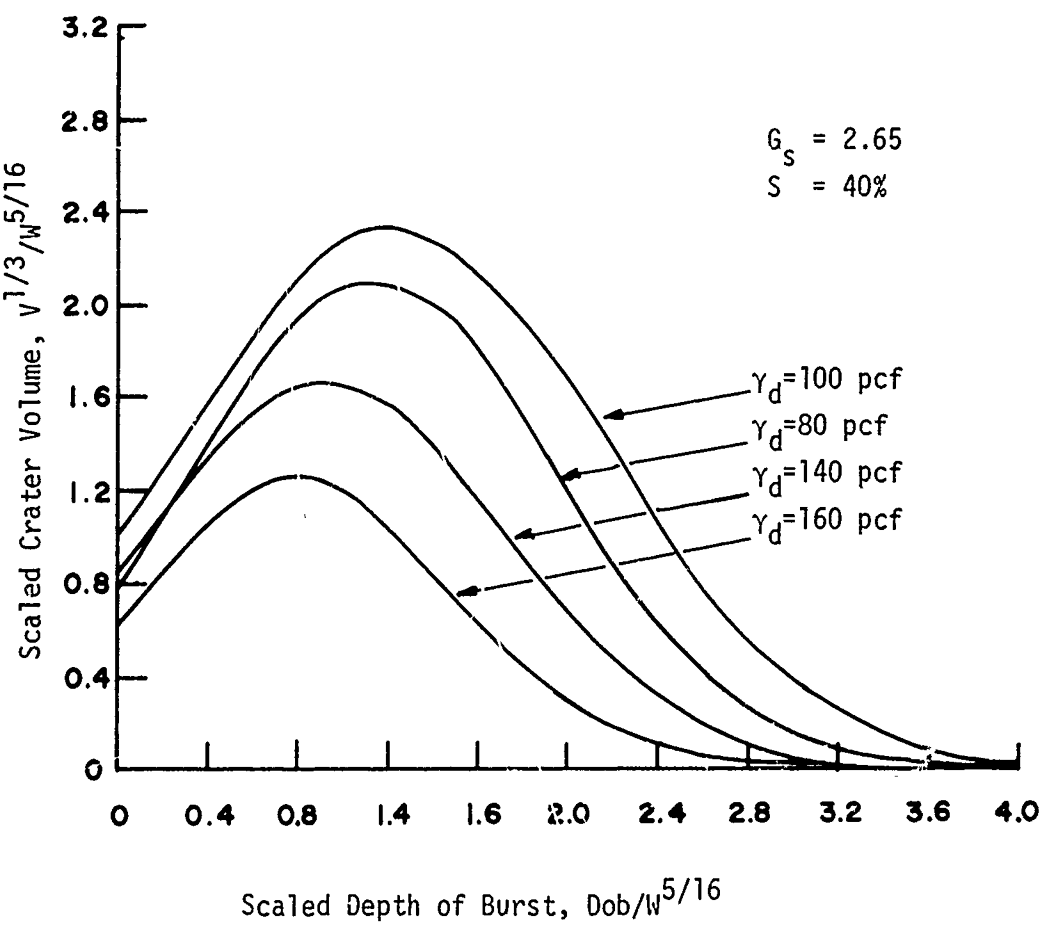


FIG. 37. CRATER VOLUME AS A FUNCTION OF CHARGE DEPTH AND DRY UNIT WEIGHT, γ_d, POUNDS/CUBIC FOOT, FOR SPECIFIC GRAVITY = 2.65 AND PERCENT SATURATION = 40

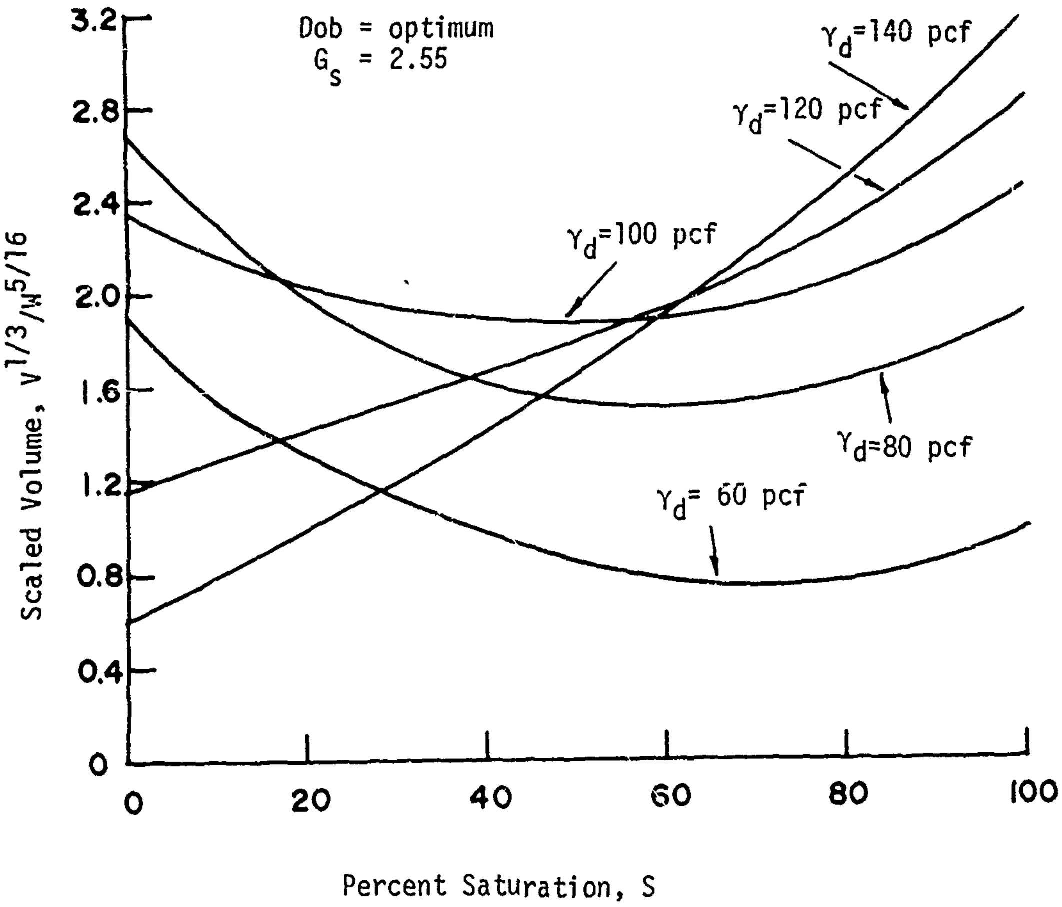


FIG. 38. CRATER VOLUME AS A FUNCTION OF PERCENT SATURATION AND DRY UNIT WEIGHT, γ_d, POUNDS/CUBIC FOOT, FOR OPTIMUM CHARGE DEPTH AND SPECIFIC GRAVITY = 2.55

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13. ABSTRACT

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Analysis of data from published cratering experiments shows the effect of soil and rock properties on the apparent dimensions of explosion-produced craters. More than 200 cratering tests and related material properties were cataloged. The data consisted of 10 nuclear events whose yields varied from 0.42 to 100 kilotons and about 200 high explosive events whose yields varied from 1 to 1 million pounds of TNT. The different test sites included materials for which the density ranged from 60 to 170 pounds/cubic foot. By regression analysis, using bell shaped curves, prediction formulas were developed for the apparent crater radius, depth, and volume as a function of charge weight and depth of burst for eight different types of materials. The bell curves were normalized using material properties and prediction equations were generated using all the data. These general equations were then studied to determine the specific effects of the material properties on resultant apparent crater dimensions. Material properties are highly important in determining the size of explosion-produced craters and some of the more important properties are unit weight, degree of saturation, shearing resistance and seismic velocity. Previous investigators have been somewhat negligent in measuring material properties for past cratering experiments and no real data analysis can be made until the variables are either controlled or measured. Material properties which should be measured for future tests should at least include the above properties and if possible the material's energy dissipation and bulking characteristics. Better yet a reasonably simple theory of cratering is needed which will better define the material properties governing cratering mechanics.

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